# Groundwater Circulation Well (GCW) Technology Evaluation at the Massachusetts Military Reservation (MMR), Cape Cod, Massachusetts

**June 1997**

Distribution is unlimited; approved for public release

Air Force Center for Environmental Excellence (AFCEE)
Technology Transfer Division

*Evaluation of*

*Groundwater Circulation Well Technology*

*at the Massachusetts Military Reservation (MMR)*

*on Cape Cod, Massachusetts*

*Parsons Engineering Science, Inc.*

*June 1997*

# NOTICE

The information in this document has been prepared for the U.S. Air Force Center for Environmental Excellence (AFCEE) under Contract F41624-94-D-8136, Delivery Order 0073. The Technology Transfer Division at the AFCEE issued this delivery order to Parsons ES to assemble and facilitate an independent expert panel review of the recirculation well technology pilot test program at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts. The purpose of the panel was to provide an independent review of the existing site data and evaluation of the recirculating wells. This document reflects the consensus view of the expert panel. Any questions regarding this report should be directed to the Technology Transfer Division at the AFCEE. The final technology selection for groundwater remediation at MMR should not be inferred from this evaluation. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

## ACKNOWLEDGMENTS

This report was prepared under the direction and coordination of James R. Gonzales of the Technology Transfer Division, Air Force Center for Environmental Excellence (AFCEE). The expert panel convened on May 19, 1997, and concluded on May 22, 1997. Presentations were made by the AFCEE Contractor (Jacobs Engineering Group), and the two recirculating well vendors (SBP Technologies/IEG-UVB Systems and Metcalf & Eddy Inc./EG&G Environmental-NoVOCs Systems). The expert panel was chaired by Dr. Robert Hinchee (Parsons ES) and included Dr. George Hoag (University of Connecticut), Dr. Paul Johnson (Arizona State University), Dr. Richard Johnson (Oregon Graduate Institute of Science and Technology), and Lt. Col. Ross N. Miller, Ph.D. (Hill Air Force Base, Utah). Other participants included Spence Smith (AFCEE MMR), Dr. Richard Peralta (Utah State University), Michael Duchesneau (Parsons ES), and Robert Polimeno (Parsons ES). Also in attendance during a portion of the panel discussion were Dr. Ian Osgerby (Army Corps of Engineers) and Dr. Denis LeBlanc (USGS). The panel would like to recognize and thank Jacobs Engineering Group, especially Mr. Jeffrey D. Carman and Ms. Rebecca Kauffman, for their invaluable assistance and support both during and after the project review sessions.

# TABLE OF CONTENTS

# TABLE OF CONTENTS
(continued)

## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **AFCEE** | Air Force Center for Environmental Excellence |
| **BOMARC** | Boeing Michigan Aerospace Center |
| **CS** | Chemical Spill |
| **DCE** | Dichloroethene |
| **DoD** | Department of Defense |
| **ESTCP** | Environmental Security Technology Certification Program |
| **ETR** | Extraction, Treatment, and Reinjection |
| **FS** | Fuel Spill |
| **FTA** | Fire Training Area |
| **GAC** | Granular Activated Carbon |
| **GCW** | Groundwater Circulation Well |
| **Jacobs** | Jacobs Engineering Group |
| **LF** | Landfill |
| **MCL** | Maximum Contaminant Levels |
| **MMR** | Massachusetts Military Reservation |
| **OpTech** | Operational Technologies |
| **MSL** | Mean Sea Level |
| **NAPL** | Non Aqueous Phase Liquid |
| **O&M** | Operation and Maintenance |
| **PCE** | Tetrachloroethene |
| **PCT** | Plume Containment Team |
| **ROD** | Record of Decision |
| **RPM** | Remedial Program Manager |
| **RWT** | Recirculating Well Technology |
| **SD** | Storm Drain |
| **SMB** | Senior Management Board |
| **STP** | Sewage Treatment Plant |
| **SVOC** | Semivolatile Organic Compound |
| **TCE** | Trichloroethene |
| **TRET** | Technical Review & Evaluation Team |
| **UTES** | Unit Training Equipment Site |
| **UVB** | Unterdruck-Verdampfer-Brunnen |
| **VOC** | Volatile Organic Compound |
| **Wasatch** | Wastach Environmental Inc. |

## REFERENCES

*Toward a Balanced Strategy to Address Contaminated Groundwater Plumes at the Massachusetts Military Reservation*, Final Report of the Technical Review & Evaluation Team, May 1996.

*Preliminary Final Design Package, Recirculating Well Study at MMR Area CS-10 East*, SBP Technologies, Inc., October 7, 1996.

*Recirculating Wells at the Massachusetts Military Reservation Site CS-10*, Metcalf & Eddy, October 1996.

*Massachusetts Military Reservation Final CS-10 Recirculating Well Pilot Test Execution Plan*, Jacobs Engineering Group Inc., October 1996.

*Preliminary Final Design Package, Recirculating Well Study at MMR Ashumet Valley*, SBP Technologies, Inc., February 10, 1997.

*Massachusetts Military Reservation Final Ashumet Valley Recirculating Well Pilot Test Execution Plan*, Jacobs Engineering Group Inc., February 1997.

*Mass Removal at CS-10*, Jacobs Engineering Group Memorandum, May 13, 1997.

*Operating Parameters - CS -10*, SBP Technologies Inc. Technical Memorandum, May 14, 1997.

*MMR Recirculating Well Pilot Test Program, Project Summary*, Jacobs Engineering Group, May 19, 1997.

*Presentation of UVB Systems to JEG and AFCEE Expert Panel*, SBP Technologies, May 19, 1997.

*NoVOCs™Pilot at MMR/CS-10, Presentation to AFCEE Expert Panel,* Metcalf & Eddy, EG&G Environmental, May 20, 1997.

*Recirculating Well Modeling Approach*, David Ward of Jacobs Engineering Group, May 20, 1997.

*Technology Demonstration of Groundwater Sparging Technique for Remediation*, Wasatch Environmental Inc., May 1, 1993.

*Field Test Data Evaluation and Technical Report of an In-Well Aeration System for BX Service Station Area of Concern at Keesler Air Force, Biloxi, Mississippi*, Wasatch Environmental, Inc., June 20, 1996.

# 1.0 BACKGROUND

## 1.1 PURPOSE OF THE PANEL REVIEW

An expert panel was convened by the Technology Transfer Division at the Air Force Center for Environmental Excellence (AFCEE) at the request of the Department of Defense's (DoD) Environmental Security Technology Certification Program (ESTCP) office to provide an independant evaluation on the current status of the recirculation well project at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts. Groundwater Circulation Well (GCW) technology has been identified as a potential remedial action for treatment of groundwater at several military and private facilities and has been suggested as a potential remedial technology at MMR. Evaluation of GCW technology at other sites has been performed by several members of this panel and this experience was considered invaluable for this evaluation. The panel's evaluation can be useful in assisting DoD environmental managers in proper utilization of this technology by outlining the proper steps or procedures for planning and collecting data for adequate evaluation of pilot studies such as the one at MMR. Since December 1996, recirculation well pilot tests have been conducted at MMR. Although this program is not complete, valuable data has been obtained that provides insight to the operation of GCW technology.

All information, data, concepts, theories, etc., provided in **Section 1.0** and **Section 2.0** of this report are based on available information that was provided to the expert panel. These sections are included in this report to familiarize the reader with some of the data presented to the expert panel during its review of the pilot testing program. **Section 3.0** and **Section 4.0** of this report are a summary of the discussions, findings, opinions, and conclusions of the expert panel. This third-party evaluation includes an assessment of the effectiveness of the GCW technology applied at MMR, associated monitoring well configuration, and other compatible remediation technologies.

## 1.2 SITE HISTORY

The Massachusetts Military Reservation is located in the upper western portion of Cape Cod, Massachusetts and occupies approximately 22,000 acres (35 square miles) of territory within the townships of Bourne, Sandwich, Mashpee, and Falmouth in Barnstable County. The upper soils in the vicinity of the MMR are predominantly the sands and silts of a pliestocene outwash plain. The major surface water features are lakes and bogs formed as kettle holes during the last glacial retreat.

The MMR consists of facilities operated by the U.S. Coast Guard, U.S. Army National Guard, U.S. Air Force, U.S. Air National Guard, Veterans Administration, U.S. Marine Corps, U.S. Department of Agriculture, and Commonwealth of Massachusetts. During the course of operations at MMR,

dating from 1934 to the present, routine military operations and accidental spills have released petroleum products, industrial solvents, sanitary wastes, and landfill leachate into the environment. The near-surface sands have allowed for the rapid infiltration of surface spills and leaks from subsurface fuel and wastewater distribution systems. Several groundwater contamination plumes have been identified as having originated at MMR and migrated off-base.

### 1.2.1 CS-10 NORTH AND SOUTH

The Chemical Spill No. 10 (CS-10) plume appears to have at least two potential sources. From 1960 until 1973, the Air Force maintained ground-to-air missiles at the Boeing Michigan Aerospace Center (BOMARC) facility at the remediation site now known as CS-10. BOMARC hazardous materials operations included maintenance of missile guidance systems, maintenance of a fuel engine system, fueling and fuel removal, and power plant operations. Since 1978, the U.S. Army National Guard has operated the Unit Training Equipment Site (UTES) at CS-10 for maintenance of armored and wheeled vehicles.

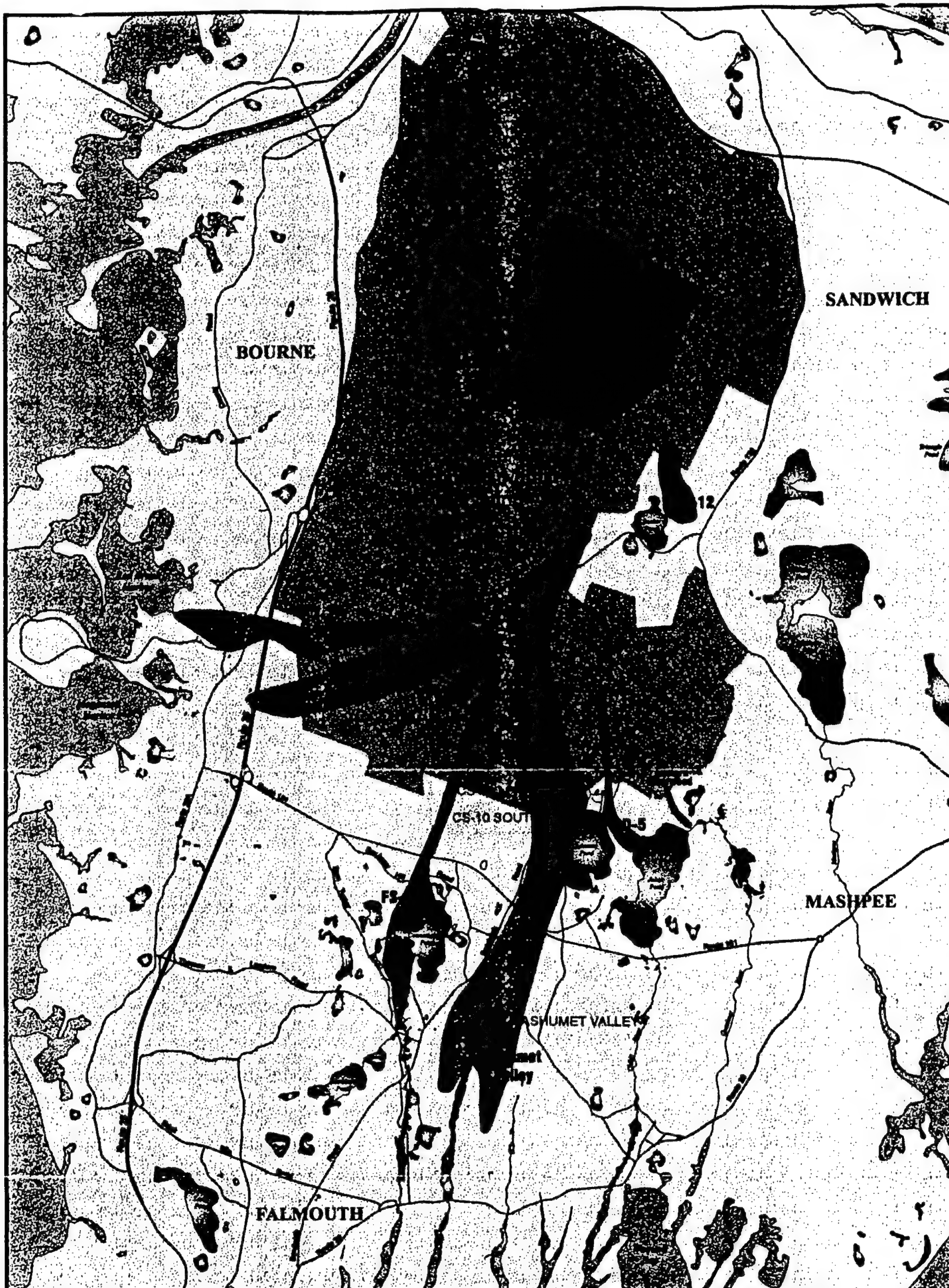
The CS-10 groundwater plume has the following characteristics:

- Groundwater migration rate - 1.0 to 1.5 feet per day
- Hydraulic gradient - 0.002
- Ground surface elevation - 80 feet above sea level
- Water table elevation - 49 feet above sea level
- Top of plume elevation - 60 feet below sea level
- Thickness of aquifer - 200 feet
- Thickness of plume - 135 feet
- Estimated horizontal hydraulic conductivity - 144 to 230 feet per day
- Stratigraphy - fine to coarse grained sand to a depth of approximately 165 feet below sea level, very fine sand, silt, and/or clay to a depth of 180 feet below sea level at which bedrock is encountered.

The latest plume delineation map, pilot test site location map, and site stratigraphy drawings are provided in the following pages. The CS-10 plume is located near the eastern edge of the MMR property line and is approximately 12,500 feet long, up to 3,600 feet wide, up to 135 feet thick, and 140 feet below ground surface at the toe. The location of the recirculating wells are also shown on each map. The following contaminants have been detected in the groundwater of the CS-10 plume (maximum concentrations in micrograms per liter (*ug/l*) are provided, from 1995 and 1996 testing data):

- trichloroethene (TCE) 2,800 *ug/l*,

- tetrachlorethene (PCE) 173 *u*g/l,
- cis-1,2-dichloroethene (1,2-DCE) 4.5 *u*g/l,
- benzene 4.5 *u*g/l,
- lead 14 *u*g/l, and
- manganese 331 *u*g/l.




# Plume Area Map

Massachusetts Military Reservation
Cape Cod, Massachusetts

0 — 8000
Scale in Feet

Air Force Center for Environmental Excellence

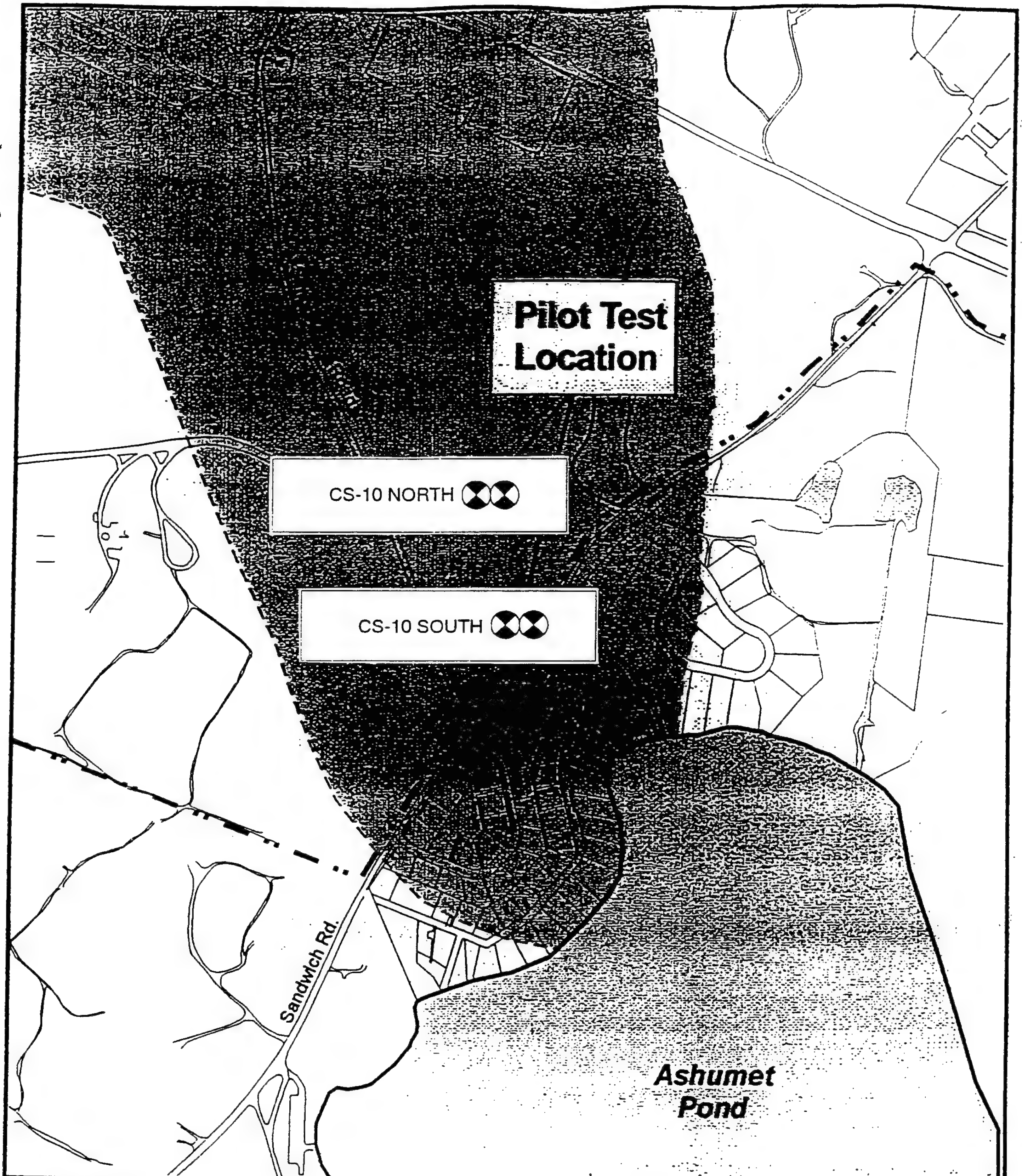
JE JACOBS ENGINEERING

Legend

| | | |
|---|---|---|
| Concentrations exceeding MCLs (Represents an individual exceedance of TCE or PCE) TCE MCL= 5 µg/L PCE MCL= 5 µg/L | Concentrations exceeding MCLs (Represents an individual exceedance of EDB) EDB MCL= 0.02 µg/L | Pond / Bog |

Source: Harwrap 1994, OPTECH 1996

JACOBS ENGINEERING April, 1997 K.K.




Legend

5 MCL

Pilot Test Location

Base Boundary

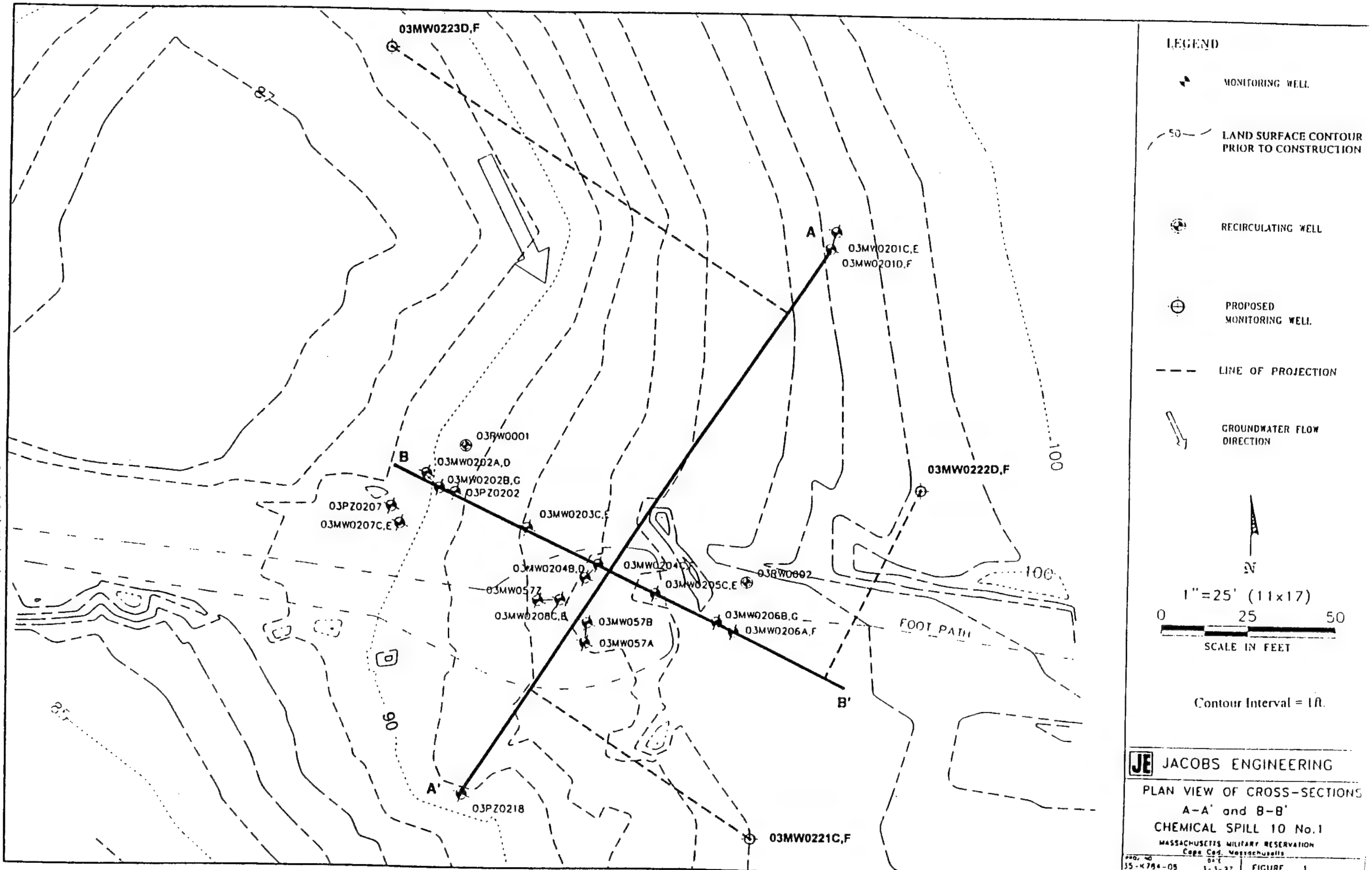
JACOBS ENGINEERING

**CS-10 Recirculating Well**
**Pilot Test Locations**

*Massachusetts Military Reservation*
*Cape Cod, Massachusetts*

01/02/97 Drawn By: KK File:..ashot1.cdr

Figure



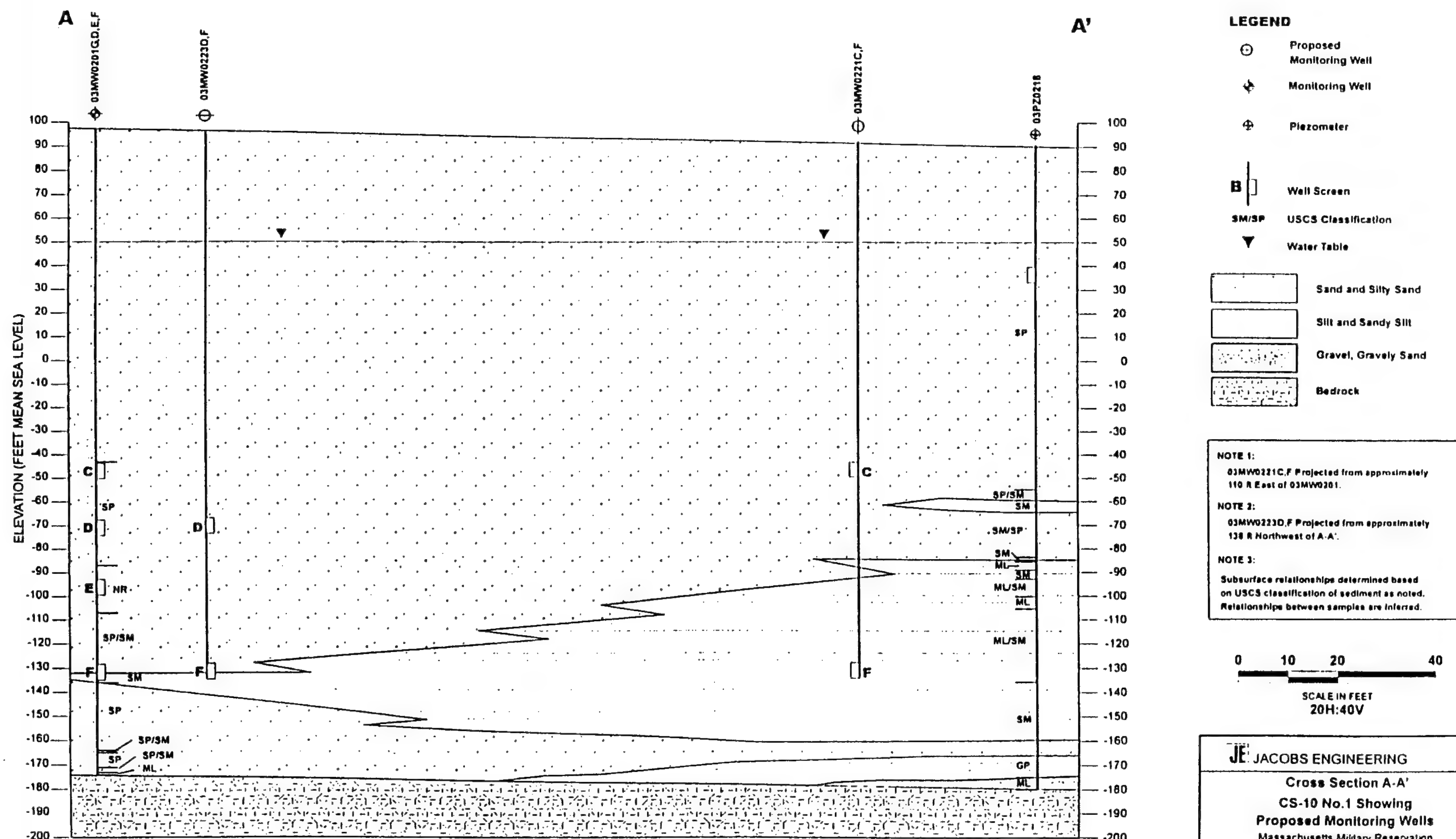

JE JACOBS ENGINEERING

PLAN VIEW OF CROSS-SECTIONS A-A' and B-B'
CHEMICAL SPILL 10 No.1
MASSACHUSETTS MILITARY RESERVATION
Cape Cod, Massachusetts

| PROJ. NO. | DATE | FIGURE |
| --- | --- | --- |
| 35-K794-05 | 3-3-97 | 1 |

I:\AUTOCAD\OCS-10\CARMAN\SITE\XSECT\PROPLAN.DWG

DRAFT




JACOBS ENGINEERING

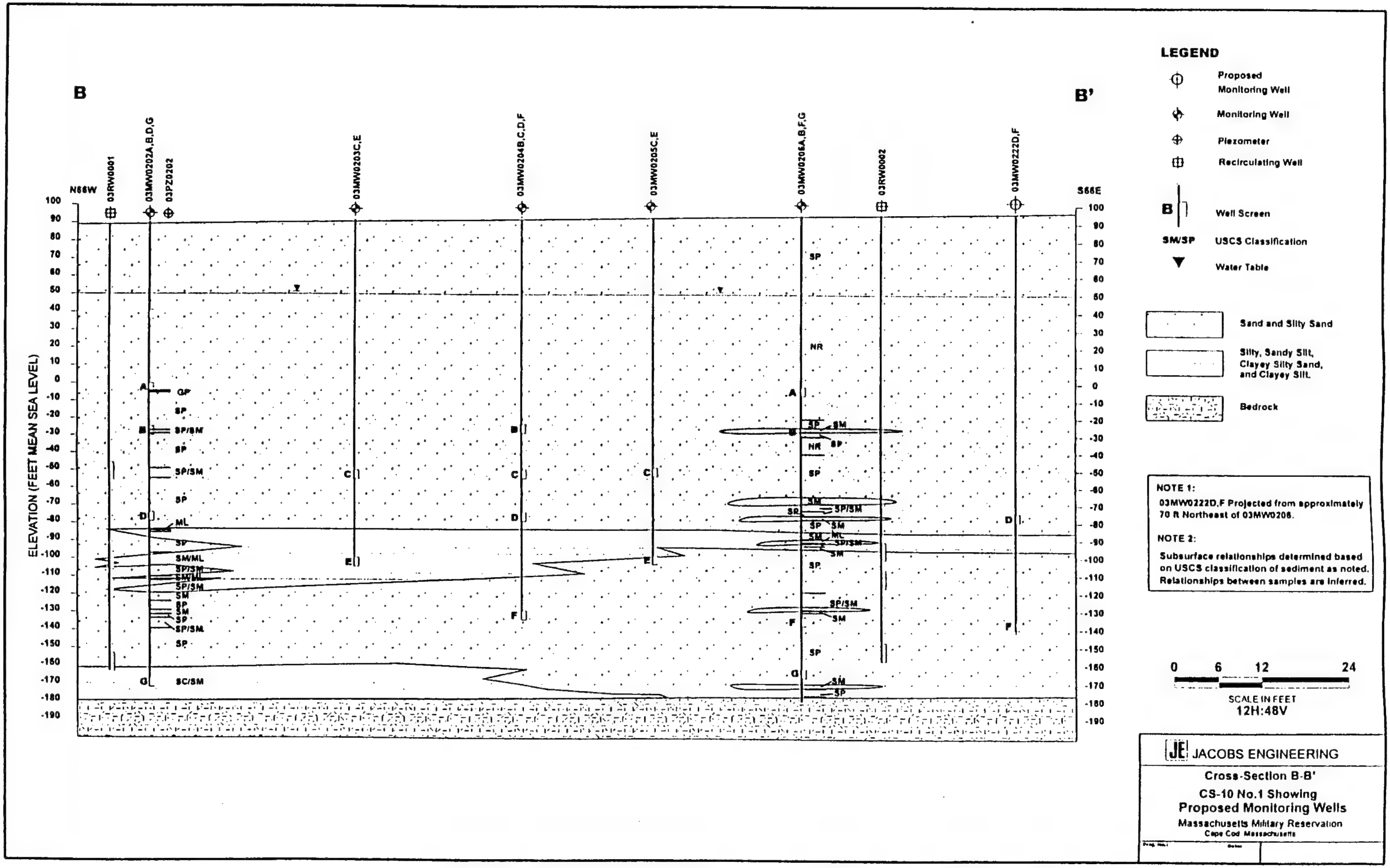
Cross Section A-A'

CS-10 No.1 Showing Proposed Monitoring Wells

Massachusetts Military Reservation

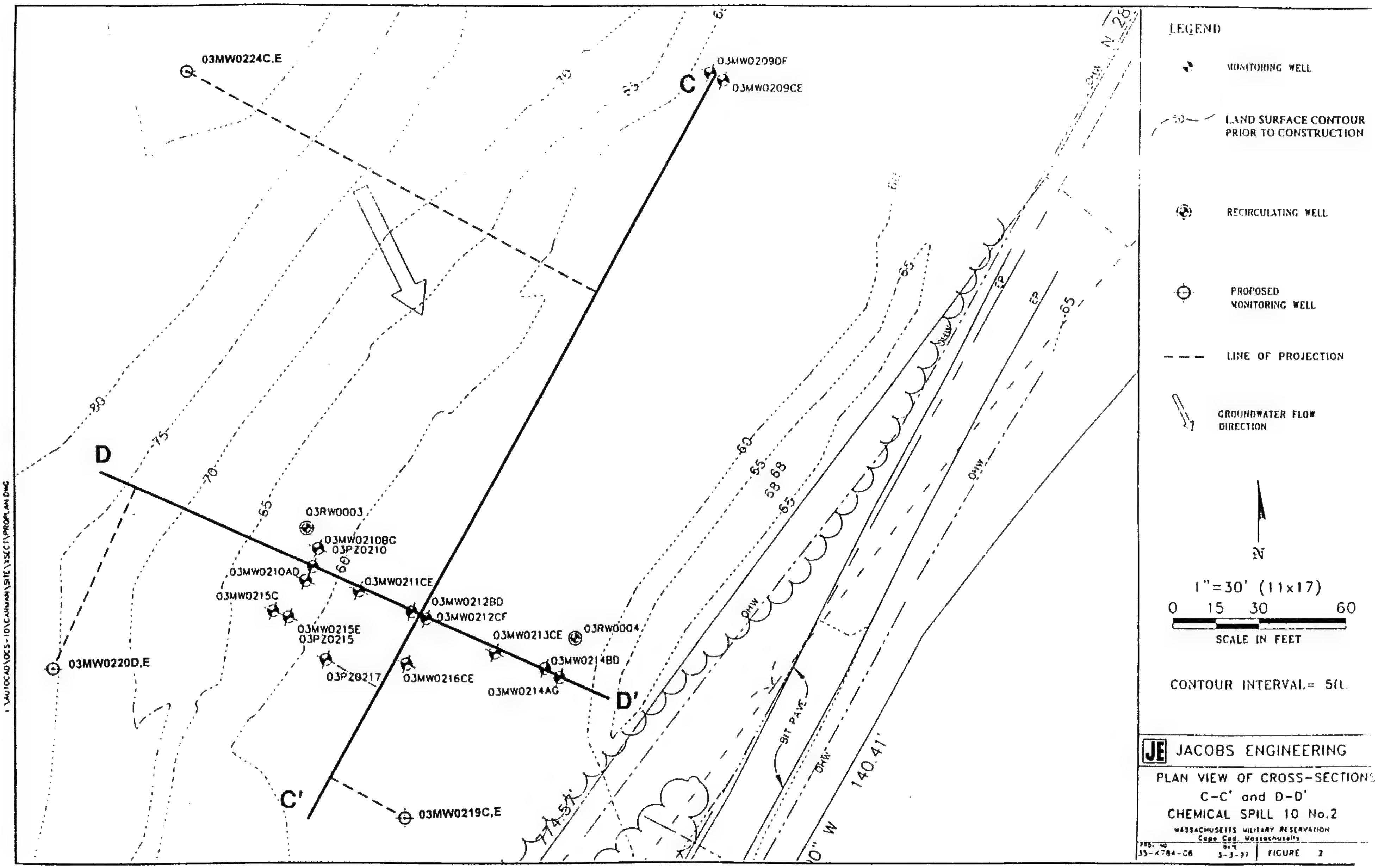
Cape Cod Massachusetts

DRAFT

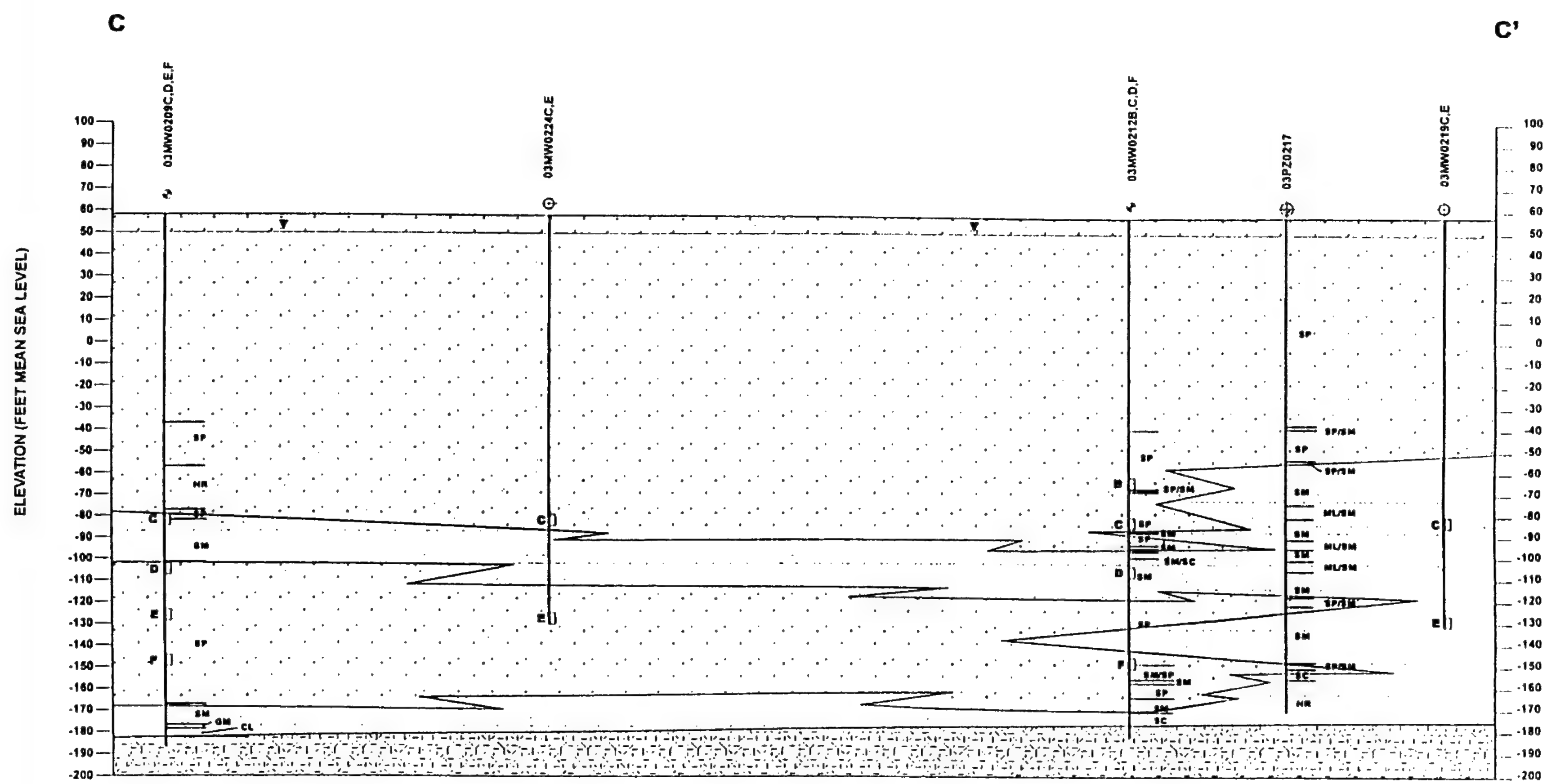


B
B'
N66W
S66E
03RW0001
03MW0202A,B,D,G
03PZ0202
03MW0203C,E
03MW0204B,C,D,F
03MW0205C,E
03MW0206A,B,F,G
03RW0002
03MW0222D,F
ELEVATION (FEET MEAN SEA LEVEL)
GP
SP
SP/SM
SM
ML
SM/ML
SC/SM
NR
SR
LEGEND
Proposed Monitoring Well
Monitoring Well
Piezometer
Recirculating Well
Well Screen
SM/SP USCS Classification
Water Table
Sand and Silty Sand
Silty, Sandy Silt, Clayey Silty Sand, and Clayey Silt.
Bedrock
NOTE 1:
03MW0222D,F Projected from approximately 70 ft Northeast of 03MW0206.
NOTE 2:
Subsurface relationships determined based on USCS classification of sediment as noted. Relationships between samples are inferred.
0 6 12 24
SCALE IN FEET
12H:48V
JE JACOBS ENGINEERING
Cross-Section B-B'
CS-10 No.1 Showing
Proposed Monitoring Wells
Massachusetts Military Reservation
Cape Cod Massachusetts


DRAFT


LEGEND
MONITORING WELL
LAND SURFACE CONTOUR PRIOR TO CONSTRUCTION
RECIRCULATING WELL
PROPOSED MONITORING WELL
LINE OF PROJECTION
GROUNDWATER FLOW DIRECTION
N
1"=30' (11x17)
0 15 30 60
SCALE IN FEET
CONTOUR INTERVAL= 5ft.
JE JACOBS ENGINEERING
PLAN VIEW OF CROSS-SECTIONS C-C' and D-D'
CHEMICAL SPILL 10 No.2
MASSACHUSETTS MILITARY RESERVATION
Cape Cod, Massachusetts
35-4784-06
3-3-97
FIGURE 2
C
C'
D
D'
03MW0224C,E
03MW0209DF
03MW0209CE
03RW0003
03MW0210BG
03PZ0210
03MW0210AD
03MW0211CE
03MW0212BD
03MW0212CF
03MW0215C
03MW0215E
03PZ0215
03PZ0217
03MW0216CE
03MW0213CE
03RW0004
03MW0214BD
03MW0214AG
03MW0220D,E
03MW0219C,E
BIT PAVE
140.41'
\AUTOCAD\CS-10\CANHAM\SITE\XSECT\PROPLAN.DWG

DRAFT




**LEGEND**

Monitoring Well
Proposed Monitoring Well
Piezometer
Water Table
B Well Screen
SP/SM USCS Classification

Sand and Silty Sand
Clayey Silt and Clayey Sand
Bedrock

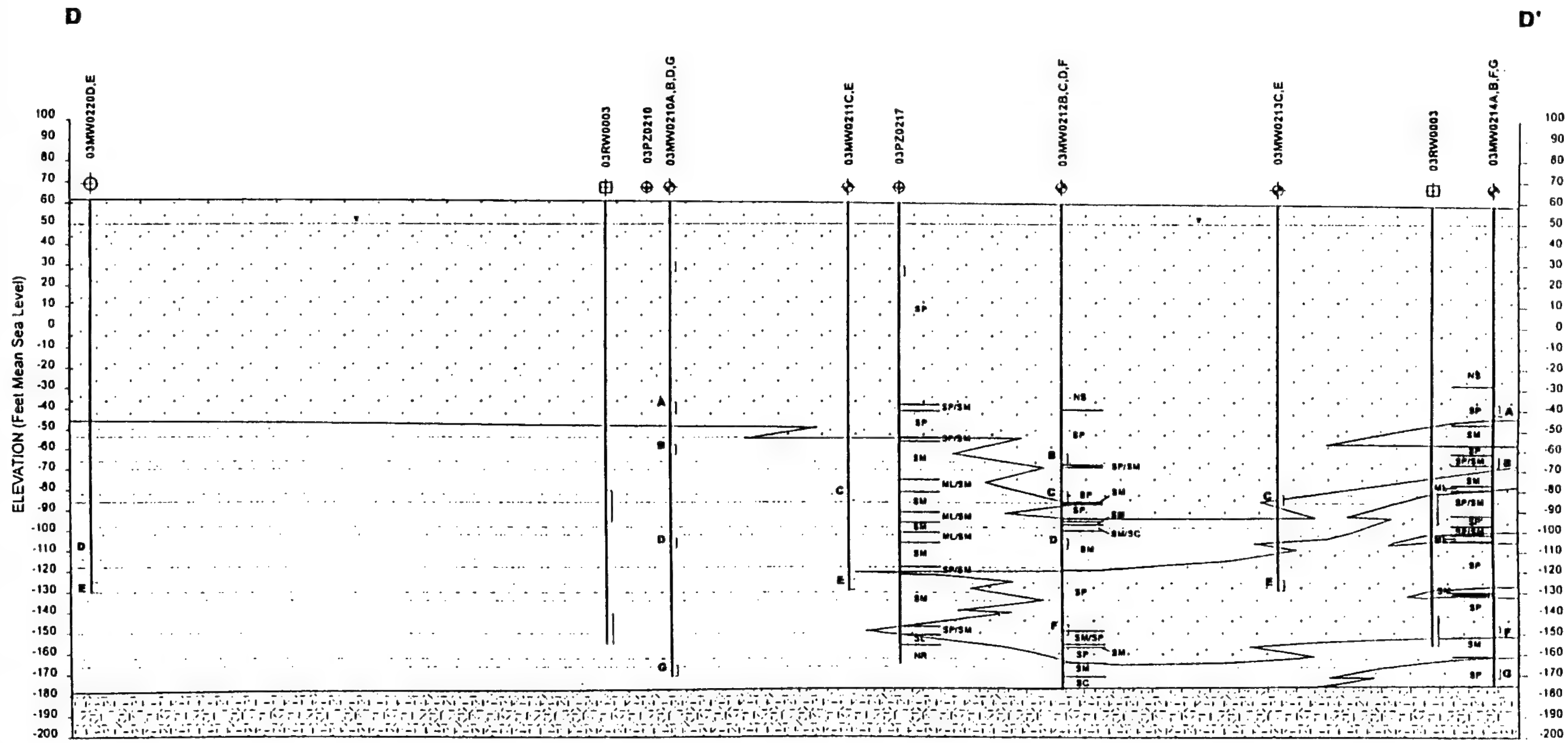
NOTE 1:
03MW0219C,E Projected from approximately 107 ft East of C-C'.
NOTE 2:
03MW0224C,E Projected from approximately 162 ft Northwest of C-C'.
NOTE 3:
Subsurface relationships determined based on USCS classification of sediment as noted. Relationships between samples are inferred.

0 25 50
SCALE IN FEET
25H:50V

JE JACOBS ENGINEERING

Cross-Section C-C'
CS-10 No.2 Showing
Proposed Monitoring Wells
Massachusetts Military Reservation
Cape Cod Massachusetts

DRAFT




**LEGEND**

- Monitoring Well
- Proposed Monitoring Well
- Piezometer
- Recirculating Well
- Water Table
- B Well Screen
- SP/SM USCS Classification
- Sand and Silty Sand
- Silt, Sandy Silt, Clayey Silty Sand and Clayey Silty
- Bedrock

**NOTE 1:**

03MW0220D,E Projected from approximately 88 FT East of D-D'

**NOTE 2:**

Subsurface relationships determined based on USCS classification of sediment as noted. Relationships between samples are inferred.

0 5 10 20

SCALE IN FEET

10H:40V

JE JACOBS ENGINEERING

**Cross-Section D-D'**
**CS-10 No.2 Showing**
**Proposed Monitoring Wells**
Massachusetts Military Reservation
Cape Cod Massachusetts

DRAFT

### 1.2.2 ASHUMET VALLEY

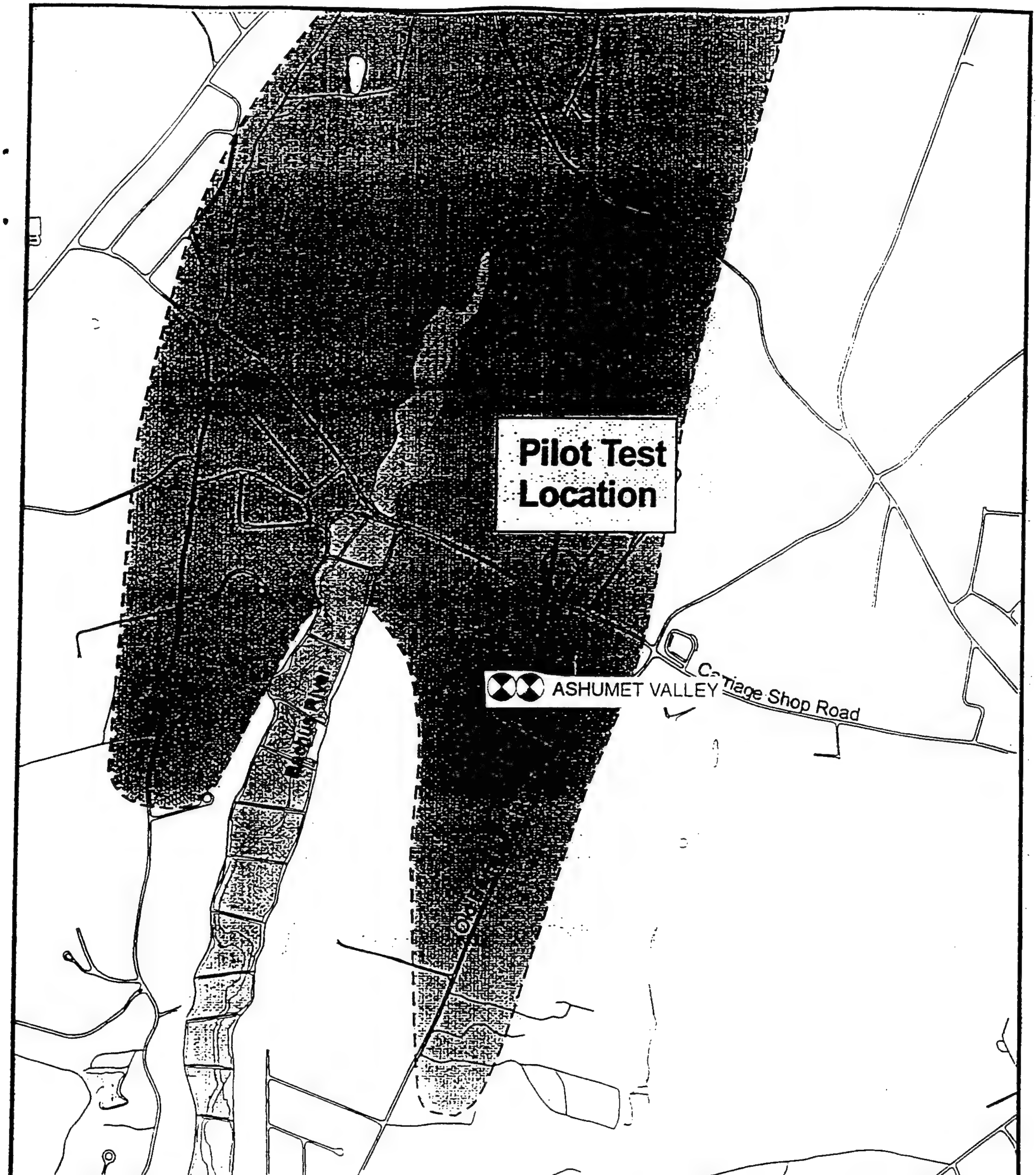
There appear to be two main source areas for the Ashumet Valley plume: the MMR Sewage Treatment Plant (STP) and the Fire Training Area-1 (FTA-1). Cleaners, solvents, paint thinners, and other volatile organic wastes may have been discharged into the MMR sanitary sewer system. These materials may have been released following treatment in the sewage system. The FTA-1 was used for fire training exercises from 1958 to 1985. Materials ignited included jet fuel, aviation gasoline, diesel fuel, waste oils, solvents, thinners, transformer oils, and hydraulic fluids. Residuals from fire training activities may have also been released.

The Ashumet Valley location has the following site characteristics:

- Groundwater migration rate - 1.0 to 1.5 feet per day
- Hydraulic gradient - 0.002
- Ground surface elevation - 57 feet above sea level
- Water table elevation - 22 feet above sea level
- Top of plume elevation - 22 feet below sea level
- Thickness of Aquifer - 200 feet
- Thickness of plume - 30 feet
- Estimated horizontal hydraulic conductivity - 144 to 230 feet per day
- Stratigraphy - fine to coarse grained sand to a depth of approximately 75 feet below sea level, very fine sand, silt, and/or clay to a depth of 180 feet below sea level. Bedrock is estimated to be in the 240 to 250 foot range below sea level.

The Ashumet Valley plume is approximately 19,000 feet long, 4,000 feet wide, 20 to 30 feet thick, and 90 feet below ground surface at the toe. The plume extends from FTA-1 south to beyond Carriage Shop Road in Falmouth. A test site location map is provided on the following page. The following contaminants have been detected in the groundwater of the Ashumet Valley plume (the maximum concentrations in micrograms per liter (*ug*/l) are provided, from 1995 testing data):

- trichloroethene (TCE) 120 *ug*/l,
- tetrachlorethene (PCE) 64 *ug*/l,
- cis-1,2-dichloroethene (1,2-DCE) 350 *ug*/l,
- benzene 9.6 *ug*/l,
- toluene 0.5 *ug*/l,
- ethylbenzene 51 *ug*/l, and
- xylenes 158 *ug*/l.




Legend

- 5 MCL
- Pilot Test Location
- Cranberry bog
- Base Boundary

N

JACOBS ENGINEERING

**Ashumet Valley**
**Recirculating Well Pilot Test Location**

*Massachusetts Military Reservation*
*Cape Cod, Massachusetts*

04/30/97 Drawn By: MDM File:..ashpilot.cdr | Figure

## 1.3 PREVIOUS EVALUATIONS AND RECOMMENDATIONS

In 1994, the Senior Management Board (SMB), the Plume Containment Team (PCT), and representatives from the regulatory agencies arrived at a consensus. The agreement was to recommend a remediation system to contain and treat 100 percent of the volatile organic compounds (VOCs) found in the seven identified plumes at MMR to below drinking water maximum contaminant levels (MCLs). Inorganics that posed unacceptable risks would be addressed as appropriate. Operational Technologies (OpTech) was selected to design such a system in accordance with the Record of Decision (ROD) for Interim Action and began work in March 1995.

### 1.3.1 OPTECH

In January 1996, OpTech submitted a 60 Percent Plume Containment Design which met the design criteria of 100 percent capture of all the plumes at their leading edges. During public review, OpTech's 60 Percent Design was considered unacceptable by all reviewing parties because 100 percent plume capture is believed to have potentially adverse impacts on Cape Cod's sensitive ecosystems and the sole-source aquifer. The design involved extraction well fences at the leading edges of each plume and returning treated groundwater to the ponds. A newly developed numerical groundwater model was used to estimate the pumping requirements of this system. The model projected a total pumping rate of approximately 27 million gallons per day which was about twice the rate that had been projected using simple analytical methods. The review process, performed by the Technical Review and Evaluation Team (TRET) identified significant changes in groundwater levels, surface water levels, and streamflow causing critical harm to ponds, natural freshwater wetlands, cranberry bogs, vernal pools, streams, and estuaries.

### 1.3.2 TECHNICAL REVIEW & EVALUATION TEAM

To avoid adverse ecosystem impacts associated with simultaneous, full containment of all plumes and to address data gaps, the TRET decided to develop and follow a design process that examines each plume individually. The TRET selected the following criteria to balance the design process:

- Avoid unacceptable toxicological risk from plume contaminants to human health and biological organisms,
- Avoid unacceptable impacts from the proposed containment strategy to the natural resources, and
- Avoid undesirable impacts on regional groundwater flow and eliminate spreading of other plumes.

Using these criteria, the TRET formulated their recommendations for each of the plumes at MMR. For the CS-10 Eastern Lobe (current location of the CS-10 North and South pilot sites), the recommendation was to pilot test and evaluate the use of GCW technology at the area of elevated contaminant concentration, particularly TCE, in the southeastern portion of the CS-10 plume that is moving towards Ashumet Pond. The TRET believed the immediate benefit to installing a recirculating well would be contaminant mass removal and/or plume capture in a contaminated area without significant drawdown of the water table or nearby ponds.

AFCEE ultimately decided, following the TRET report recommendations, to conduct recirculating well pilot tests within four plumes: CS-10, Ashumet Valley, LF-1, and SD-5 South. In December 1996 and January 1997, recirculating wells and associated monitoring wells were installed at the CS-10 North, CS-10 South, and Ashumet Valley sites. In late March 1997, AFCEE recommended an alternative approach to the Remedial Program Managers (RPMs) and followed with a letter dated April 9, 1997, that requested that plans for pilot tests at LF-1 and SD-5 South be terminated.

As a result, three pilot recirculating well systems have been installed and are in operation at MMR. Two recirculating well systems are located in the CS-10 Eastern Lobe and one system is situated in the Ashumet Valley plume. Each recirculating well system contains two recirculating wells located approximately 100 feet apart.

# 2.0 PILOT TEST PROGRAM

## 2.1 PURPOSE

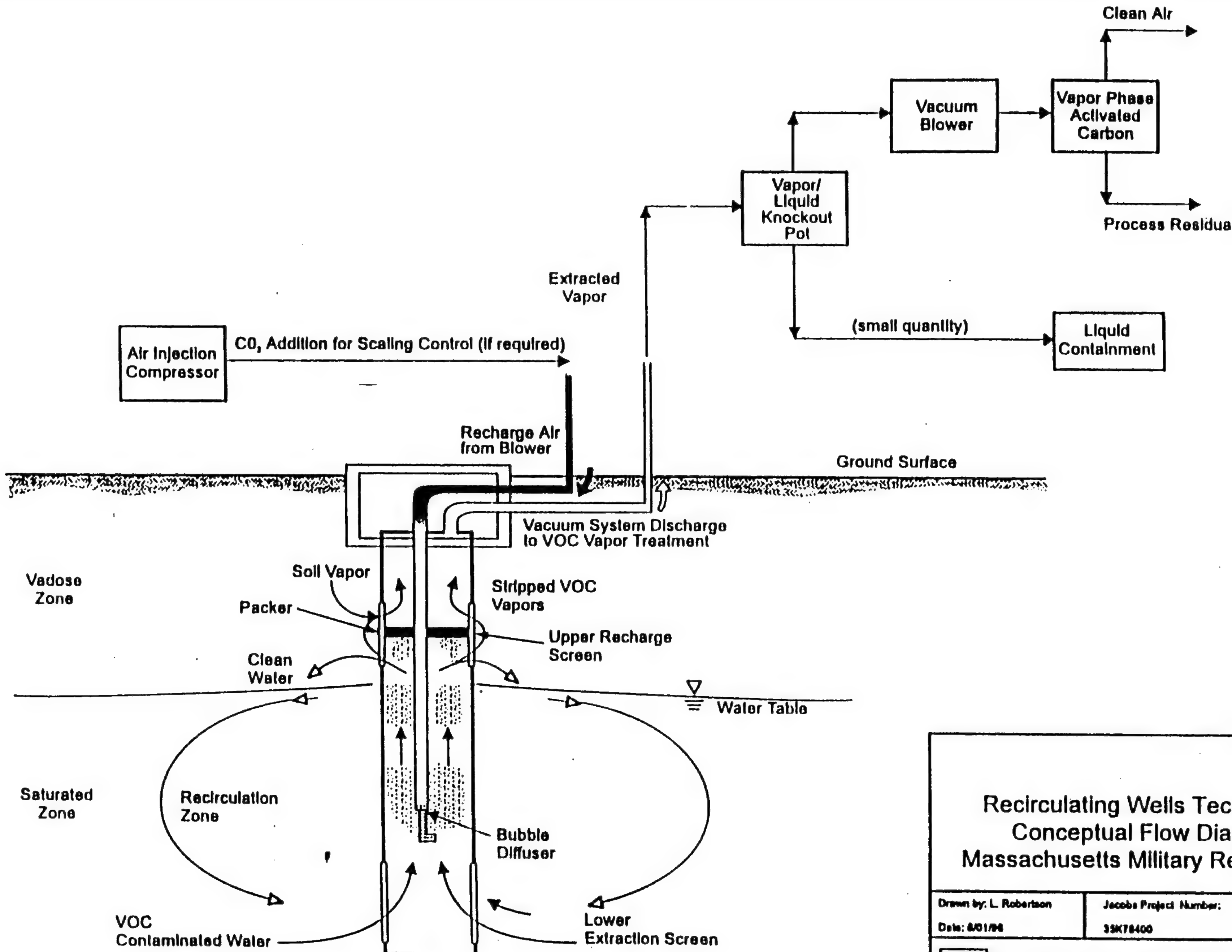
Jacobs Engineering Group (Jacobs), AFCEE's remedial design contractor for MMR, was requested to manage the overall pilot testing effort and modeling of the RWT at MMR. Commercial vendors are available that provide GCW technology. Two vendors, Unterdruck-Verdampfer-Brunnen (UVB) and NoVOCs, were selected for testing at MMR. Jacobs is managing the collection of aquifer data while the technology vendors are responsible for system operational monitoring and performance data. The following table highlights the pilot program.

| Location/ Designation | GCW Technology | Owner of Technology | Licensee | Number of Recirc. Wells | No. of Recirc. Cells |
|---|---|---|---|---|---|
| CS-10 North | UVB | IEG | SBP | 2 | 2 |
| CS-10 South | NoVOCs | EG&G | M&E | 2 | 1 |
| Ashumet Valley | UVB | IEG | SBP | 2 | 1 |

The primary objective of the pilot testing is to assess the effectiveness GCW technology in reducing concentrations of DCE, PCE, TCE, and other volatile organics in the groundwater. Additionally, Jacobs was tasked with assessing the relative effectiveness of GCW technology versus conventional extraction, treatment, and reinjection (ETR) technology, and to compare the two different recirculating well technologies.

## 2.2 DESCRIPTION OF GROUNDWATER CIRCULATION WELLS

GCW technology is a recent groundwater treatment technology for in-situ remediation of volatile organic compounds. The system removes VOCs from aquifers through a combination of dissolution from the soil matrix, air stripping of dissolved contaminants, and, in some cases, enhanced aerobic biodegradation. The process relies on contaminated groundwater circulating through the well. Groundwater enters one screened interval or intervals where it is treated, usually by air stripping, and then discharged through a different screened interval or intervals . Water is treated, usually by aeration, to strip the VOCs within the well. As a result, extraction, treatment, and reinjection all occur within a single well. Aeration could increase dissolved oxygen levels which may also stimulate increased aerobic microbial activity, possibly reducing contaminant levels. The following figure is a conceptual flow diagram of GCW technology. A key to the technology is to develop a circulation cell in the aquifer, allowing some fraction of the treated water to make multiple passes through the well. The vertical circulation of groundwater can be attained with multiple wells. It is




Recirculating Wells Technology
Conceptual Flow Diagram
Massachusetts Military Reservation

| Drawn by: L. Robertson | Jacobs Project Number: | File Name: |
|---|---|---|
| Date: 8/01/96 | 35K78400 | f304-03 cdr |


JACOBS ENGINEERING GROUP INC.
318 East Inner Road, Otis ANGB, Massachusetts 22542

also possible to operate a multi-screened extraction/injection system without creating a circulation cell. Circulation wells as defined in this report is limited to the treatment technology where a single well invokes a circulation cell in the aquifer in which some fraction of the well effluent is recycled back to the well influent.

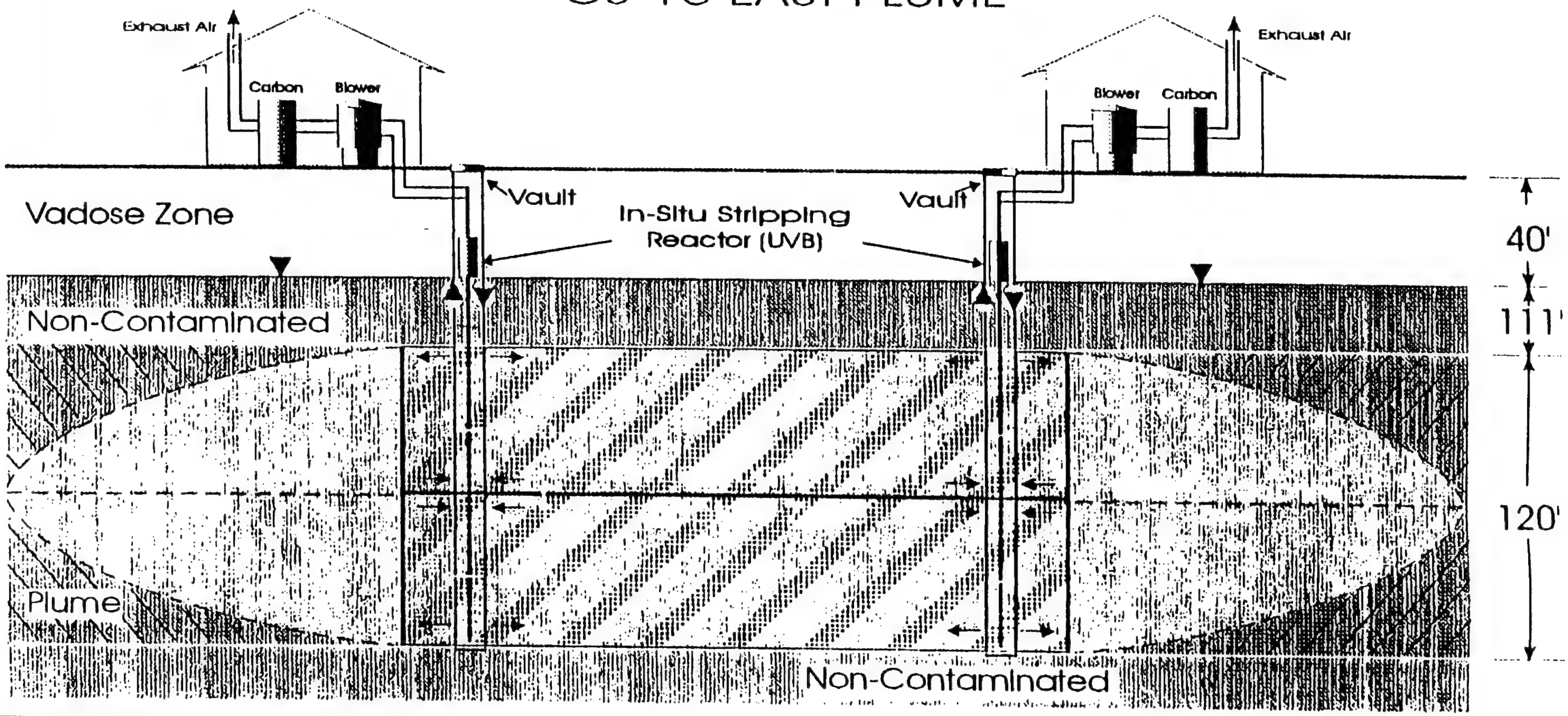
### 2.2.1 UVB CIRCULATION WELL SYSTEM

The UVB technology includes a groundwater circulation well, with a screened intake section and a screened discharge section, an in-well groundwater stripping reactor, an aboveground blower used to generate the negative pressure on the well to enhance liquid/vapor stripping equilibria, and a vapor-phase contaminant collection system. The control and granular activated carbon (GAC) air treatment system is located in a nearby aboveground building. Contaminated groundwater enters the intake screen and is pumped to the stripping reactor, where volatile contaminants are transferred to air that has been introduced to the sealed stripping reactor. Once sufficient treatment has occurred the treated water flows by gravity to the discharge screen section of the circulation well. A packer separates the intake section from the discharge section of the circulation well.

The stripping reactor operates under reduced atmospheric pressure that is created by the aboveground blower. As a result of the reduced pressure conditions of the reactor, fresh clean air is allowed to enter the stripping reactor through a drop pipe at the bottom of the stripping reactor. The stripping reactor is a metal plate with small pinholes. Concentric circular elongated plates are attached to the bottom metal plate to increase treatment time. Contaminated water is pumped onto the bottom pinhole metal plate, located above a groundwater collection chamber, and migrates cocurrently up the circular plate as the clean air and water mix. As the air passes through the pinhole plate and mixes with the water, contaminants are transferred from the water to the air. Both the air and the water move in the same upward direction therefore the stripping process is considered to be cocurrent. The offgas, air and volatile contaminants, are removed from the reactor and treated separately from the stripping process in an aboveground carbon adsorption unit.

Groundwater circulation is achieved by downhole submersible electric pumps. The UVB system installed at CS-10 is a double stacked circulation system that consists of two discharge screen sections, located in the upper and lower sections of the plume, and an intake screen section positioned in the middle of the discharge screens. Water is pumped from the two intake screened sections to the stripping reactor via a central pipe. The thickness of the plume and the rapid groundwater velocities required this stacked configuration of that produces two circulation cells within the aquifer in order to achieve the goal of plume containment. The following figure provides a conceptual flow diagram of the UVB system.

# CONCEPTUAL UVB TECHNOLOGY
# VERTICAL GROUNDWATER CIRCULATION WELLS
# CS-10 EAST PLUME




| | |
|---|---|
| Contaminants: | TCE 2800 ppb* |
| | * Sampling date July 1, 1996 at MW-57 |
| Ground Surface Elevation: | Datum 0 |
| Water Table Elevation: | 40 BLS |
| Plume Top Elevation: | 151BLS |
| Plume Thickness: | 120 Feet |

Proprietary Information

SCALE: NOT TO SCALE

SBP Technologies, Inc.

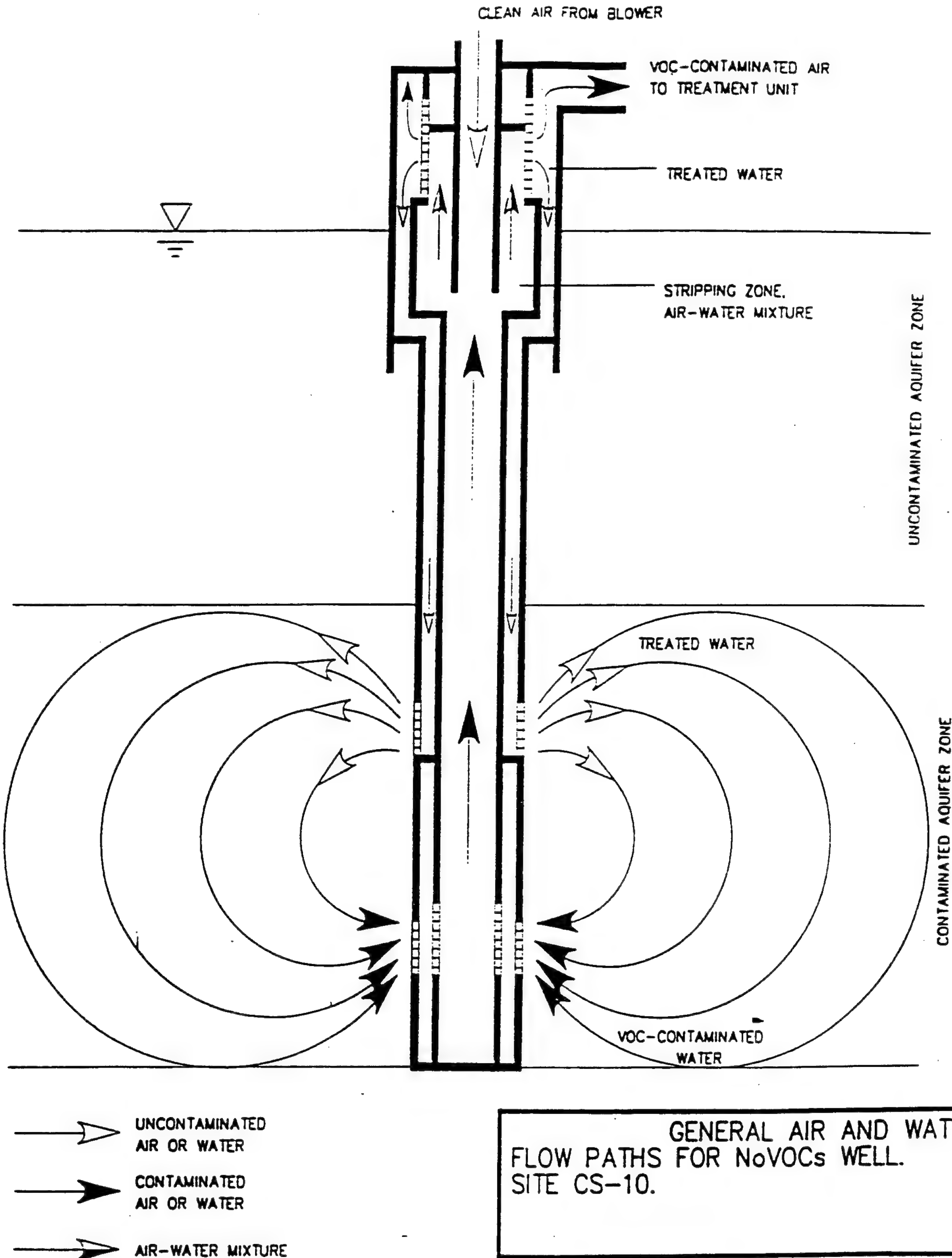
*Environmental Engineers and Bioremediation Specialists*

The UVB system installed at the Ashumet Valley site is a single circulation well configuration, not a stacked double configuration as at the CS-10 North location. As a result, the Ashumet Valley circulation well has two screened intervals only. The lower screen serves as the system intake and the upper screen serves as the discharge. The essential features of the system, such as the stripping reactor and the aboveground air treatment system, is the same as at the CS-10 North location.

### 2.2.2 NoVOCs CIRCULATION WELL SYSTEM

Although the NoVOCs technology is similar in some respects, there are some notable differences from the UVB system. The conceptual flow diagram of the NoVOCs system is provided in the following figure. The NoVOCs objective is to establish circulation cells in the aquifer similar to UVB. NoVOCs, however, relies on injected pressurized air to drive an air lift pump that also aerates the water as it is pumped up the well. As a result, NoVOCs operates under pressure rather than vacuum, and has no mechanical pump operating within the circulation well. As with UVB, the stripping process is cocurrent. Both water and air flow in the same direction up the interior of the well. As this mixture of air and water move up the well volatile organic contaminants are transferred from the water to the air. The contaminant laden air is then removed from the well and treated with GAC in a nearby aboveground treatment building. Unlike the UVB design, the NoVOCs design at the CS-10 South location involves only one circulation cell that encompasses the entire plume thickness. The lower screen of the well serves as the system intake and the upper screen, while still located inside the contaminated aquifer, serves as the treated water discharge.

Another significant difference is that the NoVOCs design recycles the air back down the well after volatile contaminants have been removed through the GAC filter. The UVB design is different as it discharges clean, filtered air to the atmosphere. The NoVOCs closed loop system takes advantage of the temperature increase that occurs as the air is compressed on the discharge side of the blower. This increase in temperature increases the stripping efficiency between the water and the air. However, the increased air temperature also has an increased capacity for water that may cause increased water condensation prior to or at the GAC filters. Both the UVB system and the NoVOCs system use aboveground controls, an air blower, and vapor treatment systems (GAC) located in adjacent small buildings.




GENERAL AIR AND WATE
FLOW PATHS FOR NoVOCs WELL.
SITE CS-10.

M&E METCALF & EDDY

| DRAWN BY: | CHECKED BY: | DATE: | VERT. SCALE: | PROJECT NO.: | FILE: |
|---|---|---|---|---|---|
| J. ENGLISH | | | NONE | N013 | CS10_F08.DW |

### 2.2.3 OTHER CIRCULATION WELL TECHNOLOGIES

UVB and NoVOCs are not the only groundwater circulation well technology vendors. For example, a circulation well density-driven convection system has been designed and is offered commercially by Wasatch Environmental Inc. (Wasatch). The Wasatch technology is similar to NoVOCs in that it uses pressurized air injection to drive both an air lift pumping action and to aerate the water. Wasatch installations tend to be simpler than NoVOCs often consisting only of the dual screened well, and an aeration tube set at the appropriate depth. The objective of developing a circulation cell in the aquifer is similar to UVB and NoVOCs. Please refer to the schematic of the Wasatch system. Note, the Wasatch system is currently undergoing a field demonstration at the BX Gas Station at Kessler AFB under contract to AFCEE's Technology Transfer Division.

## 2.3 DESCRIPTION OF THE PILOT TEST PROGRAM

Both the UVB and NoVOCs recirculating well systems at the CS-10 North and South sites respectively began operation on December 20, 1996. The Ashumet Valley UVB system began operation on February 24, 1997. The remainder of this document, including both data presented and pilot study discussion, focuses primarily on the CS-10 North and South locations. The panel felt that the dilute concentrations found in the aquifer where the UVB system was installed at the Ashumet Valley site were too low for definitive conclusions to be reached. The amount of data for this site was much less than that available for the CS-10 plume. However, the panel did agree that some inferences could be made about the Ashumet Valley system based on the review of the UVB system at CS-10 North.

### 2.3.1 AQUIFER MONITORING

Aquifer monitoring is being performed by Jacobs upgradient, downgradient and within the extent of the expected zone of circulation. This effort is being performed concurrently with the collection of system operational data that has been collected by each of the technology vendors for their system. Since the technology vendors understand the operation of their system it was determined that each vendor should be responsible for collection the operational data. In the end, the combination of both the aquifer monitoring data and the RCW system operational data will yield a total understanding of both the operational performance of each system and the effect that the system has had on the aquifer.

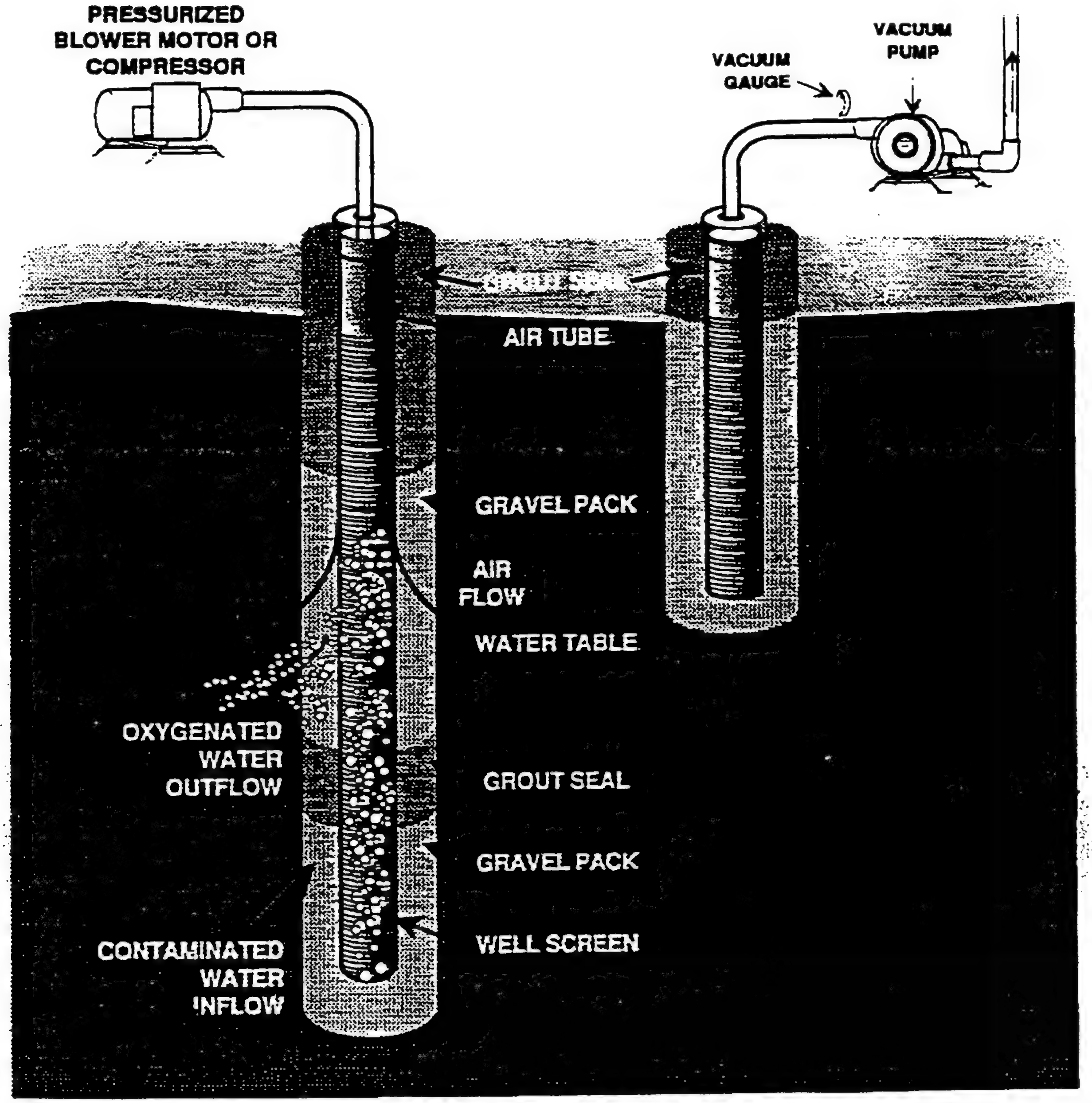



**FIGURE 5: SCHEMATIC OF DENSITY-DRIVEN CONVECTION SYSTEM WITH VAPOR EXTRACTION**

WEI PROPOSAL

The objective of the aquifer monitoring program is to collect aquifer information that will be used to support the groundwater modeling effort and will evaluate the performance of the circulation wells. The monitoring program involves collection of :

- Hydraulic pressure data from upgradient, downgradient and within the area where the circulation cell(s) are expected to develop will be used to confirm the results of the modeling effort and determine the presence of and the extent of the circulation cells,
- Upgradient aquifer contaminant concentration data will determine if the concentrations that are migrating into the circulation cell (s) have remained constant over the evaluation period,
- Downgradient aquifer contaminant concentration data will determine if the circulation wells are achieving the expected reductions.

Groundwater sampling has been performed in accordance with the following schedule:

| Location | Baseline (Startup) | Number of Wells | Sampling Round 1 | Sampling Round 2 | Sampling Round 3 | Sampling Round 4 |
|---|---|---|---|---|---|---|
| CS-10 North | Dec 10 - 19 (Dec 20) | 26 | Jan 14 - 27 | Feb 21 - 26 | Mar 21 - 31 | Apr 21 - 29 |
| CS-10 South | Dec 9 - 16 (Dec 20) | 26 | Jan 14 - 27 | Feb 21 - 26 | Mar 21 - 31 | Apr 21 - 29 |
| Ashumet Valley | Jan 16 (Feb 24) | 27 | Mar 17 - 21 | Apr 30 - May 2 | | |

Additional monthly sampling rounds could continue if it is determined that pilot study should be extended. The pilot study could be extended if the development of the circulation cell (s) have not been complete or the expected changes in concentration from monitoring wells within the circulation cell have not been fully realized due to greater than expected aquifer travel times. It is also possible to extend the operation of the circulation wells if the technology evaluation identifies positive benefits to continued operation of the system. If, for whatever reason, continued operation of the RCW occurs then additional monitoring would most likely continue in support of the RCW operation.

During the early stages of the monitoring program, it was determined that the anticipated groundwater flow direction was different from what was determined from field measurements. As a result, the circulation wells at both CS-10 North and CS-10 South locations were not perpendicular to groundwater flow. This meant that one circulation well would be slightly downgradient of the other one, providing a slightly more complicated hydraulic picture. Further, monitoring wells that

were installed were not perfectly upgradient or downgradient of the circulation wells, providing additional uncertainty to the evaluation. To alleviate and minimize this situation, a total of twelve (12) additional monitoring wells, six (6) at each CS-10 site, were installed. The proposed location of these additional monitoring wells are shown on the site plan for each CS-10 site. These wells were being installed in May and therefore no data was available for the review panel. The actual location of each well was not available but is anticipated to be close to the designated proposed location.

At the UVB, CS-10 North site, two (2) wells, 03MW0221C and 03MW0221F, were proposed at a location approximately 140 feet directly downgradient of and midway between the circulation treatment wells, 03RW0001 and 03RW0002. The location of these two monitoring wells are expected to be beyond the 116 foot downgradient stagnation point that would be produced by the operation of the two circulation wells. The anticipated aquifer screened interval for 03MW0221C is -50 to -55 feet, msl. The anticipated aquifer screened interval for 03MW0221F is lower at -140 to -145 feet, msl. These locations will provide aquifer quality information at both the upper and lower portions of the contaminated zone. If UVB system is effective then the concentration of contaminants in these wells should begin to decrease.

Two (2) wells, 03MW0222D and 03MW0222F, were located approximately 65 feet crossgradient on either side of the two circulation wells, 03RW0001 and 03RW0002. The location of these two monitoring wells are expected to be within 80% of the crossgradient stagnation point that would also be produced by the operation of the two circulation wells. The anticipated aquifer screened interval for 03MW0222D is -75 to -80 feet, msl. The anticipated aquifer screened interval for 03MW0222F is lower at -135 to -140 feet, msl. These locations will provide both pressure head and aquifer quality information at the midpoint of the expected upper and lower circulation cells.

Finally, two (2) wells, 03MW0223D and 03MW0223F, are to be located approximately 150 feet upgradient of the two circulation treatment wells. The location of these two monitoring wells are expected to provide a baseline of influent concentrations moving into the circulation wells capture zones. The anticipated aquifer screened interval for 03MW0223D and 03MW0223F have not been set but will be based upon the highest concentration of contaminants observed in the aquifer.

At the NoVOCs, CS-10 South site, two (2) wells, 03MW0219C and 03MW0219E, were proposed at a location approximately 152 feet directly downgradient of and midway between the circulation treatment wells, 03RW0003 and 03RW0004. The location was established based upon the presence of overhead power lines and it is not known if these two monitoring wells will be beyond the downgradient stagnation point. The anticipated aquifer screened interval for 03MW0219C is -80 to -85 feet, msl. The anticipated aquifer screened interval for 03MW0219E is lower at -125 to -130

feet, msl. These locations will provide piezometeric head and aquifer quality information at both the upper and lower portions of the contaminated zone. The upper location will be indicative of groundwater that was released from the discharge screen following treatment. The lower screened zone will provide information about the conditions within the circulation cell. If the NoVOCs system is effective then the concentration of contaminants at the upper screened interval should begin to decrease.

Two (2) wells, 03MW0220D and 03MW0220F, were located approximately 100 feet crossgradient on the side of the circulation well, 03RW0003. The location of these two monitoring wells are expected to be within 67% of the 150 foot crossgradient stagnation point that would be produced by the operation of the circulation well. The anticipated aquifer screened interval for 03MW0220D is -105 to -110 feet, msl. The anticipated aquifer screened interval for 03MW0220F is lower at -125 to -130 feet, msl. These locations will provide both pressure head and aquifer quality information within the expected circulation cell.

Two (2) wells, 03MW0224C and 03MW0224E, are to be located approximately 200 feet upgradient of the two circulation treatment wells. The location of these two monitoring wells are expected to provide a baseline of influent concentrations moving into the circulation wells capture zones. The anticipated aquifer screened interval for 03MW0224D and 03MW0224E have not been set but will be based upon the highest concentration of contaminants observed in the aquifer.

Groundwater flow model development has been performed using the existing monitoring well network data. The data from these monitoring wells that are to be installed in May 1997, will used to check the initial model calibration and finalize aquifer parameterization of the model prior to final calibration.

The current monitoring program involves collection of a variety of data. Field measurements include: water level, piezometeric head, pressure head, pH, temperature, conductivity, dissolved oxygen and redox potential. Groundwater samples from all monitoring wells are submitted to an approved laboratory and analyzed for volatile organic compounds. During the initial portion of the monitoring program groundwater samples were collected for semi-volatile organic compounds but was discontinued early in the program. Continuous soil samples were collected during the installation of the monitoring wells. Analyses included pH, triaxial permeability at Ashumet Valley only, bulk mineralogy, porosity, grain size, total organic carbon, VOCs, semi-volatile organic compounds, and metals.

Charts and graphs are provided at the end of this section based on the aquifer monitoring data collected to date. This includes:

- TCE cross-sections,
- change in dissolved oxygen cross-sections, and
- water level changes from static to operational cross-sections.

### 2.3.2 SYSTEM OPERATIONAL MONITORING

The technology vendors monitor the operation and performance of their systems. Generally, operational parameters to be monitored include fresh air inlet pipe velocity, air temperature, well head vacuum or pressure, blower flow rates, emission flow rates, and packer pressure. Air monitoring is performed to determine the rate of carbon usage. Air sampling is conducted using a photoionization detector at a sampling port between the carbon canisters. Operational information for the circulation well sites through late April is presented below.

CS-10 North (UVB)

| | |
|---|---|
| • Pumping rate for Well #1 | 40 gallons per minute (12/21/96 to 2/5/97) |
| | 60 gallons per minute (2/6/97 to 4/14/97) |
| • Pumping rate for Well #2 | 40 gallons per minute (12/21/96 to 2/5/97) |
| | 60 gallons per minute (2/6/97 to 4/14/97) |
| • Total gallons pumped | 7,884,000 |
| • Downtime since startup | 7 days for Well #1 (O&M and single well testing) |
| | 8.8 days for Well #2 (O&M and single well testing) |
| • Airflow | 850 to 1,150 cubic feet per minute for Well #1 |
| | 830 to 1,100 cubic feet per minute for Well #2 |
| • Air to Water Ratio | 135:1 (approximately) |

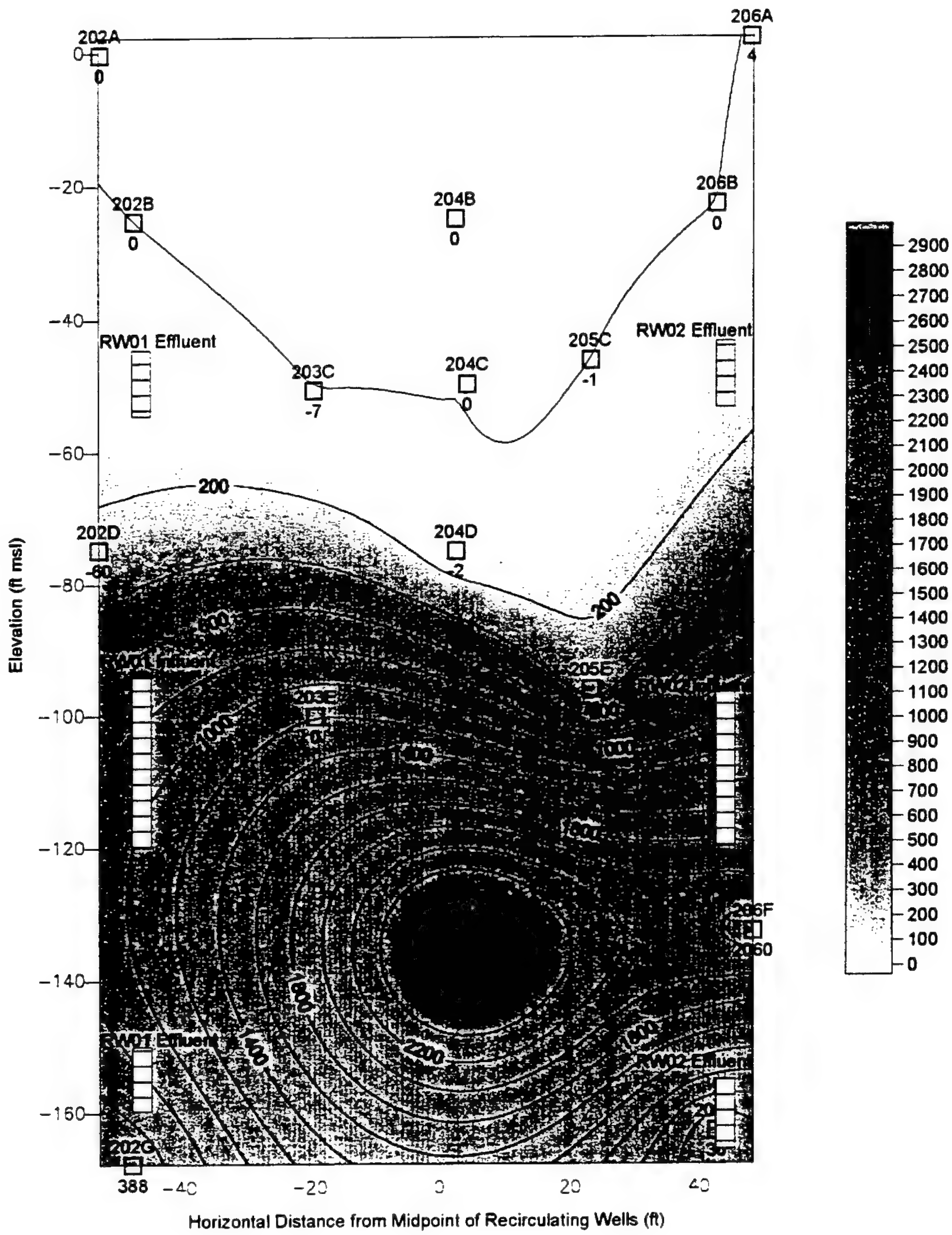
CS-10 South (NoVOCs)

| | |
|---|---|
| • Pumping rate for Well #3 | 180 gallons per minute |
| • Pumping rate for Well #4 | 150 gallons per minute |
| • Total gallons pumped | 39,247,200 |
| • Downtime since startup | 57.5 days for Well #3 (O&M and single well testing) |
| | 61.5 days for Well #4 (O&M and single well testing) |
| • Design air to water ratio | 20:1 |
| • Actual air to water ratio | not provided (probably greater than 20:1) |

Stripper performance are included which present influent concentrations, effluent concentrations, and stripper removal efficiencies.

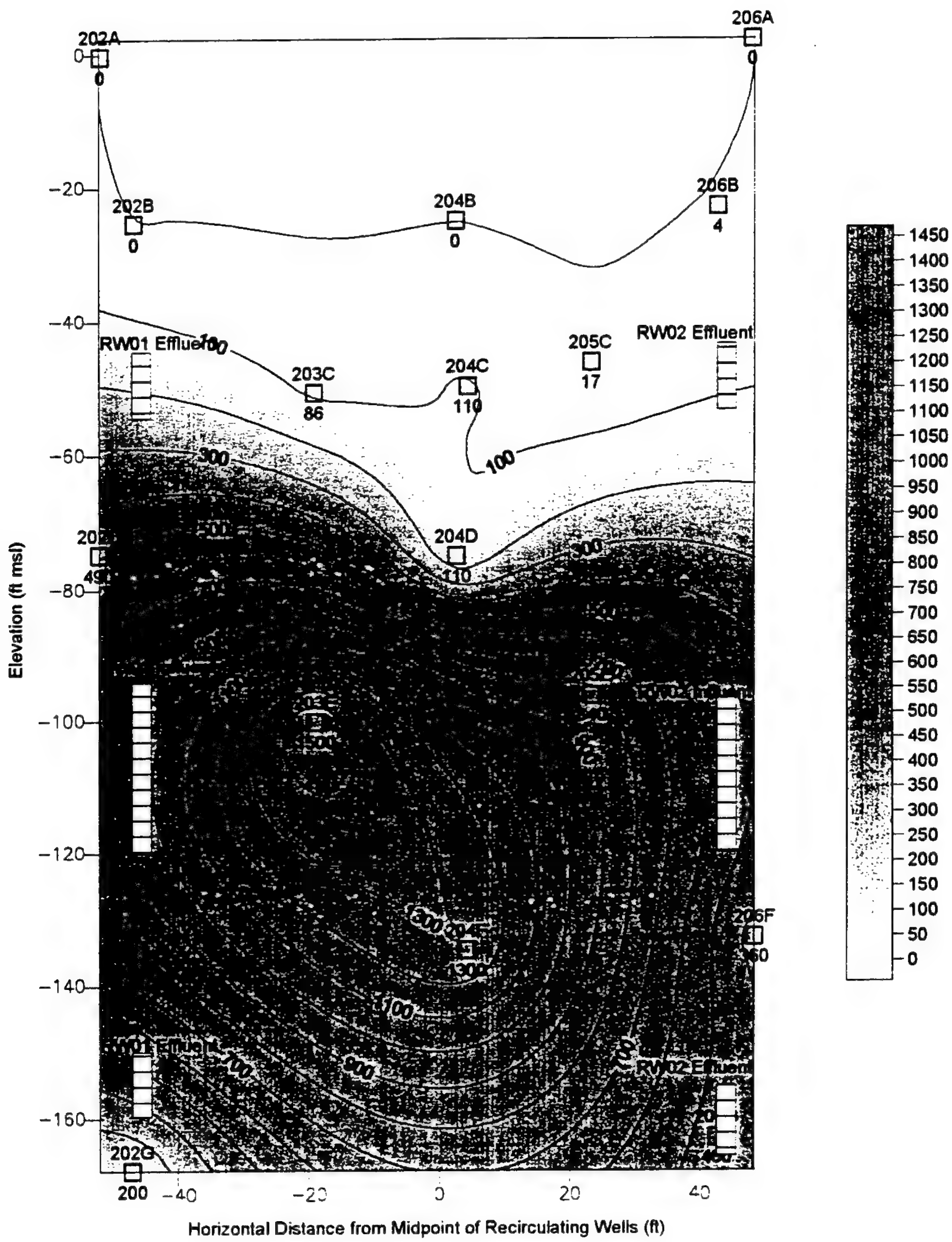
## Recirculating Well Pilot Test: CS-10 No.1

### Section B-B' TCE (ug/L) Baseline



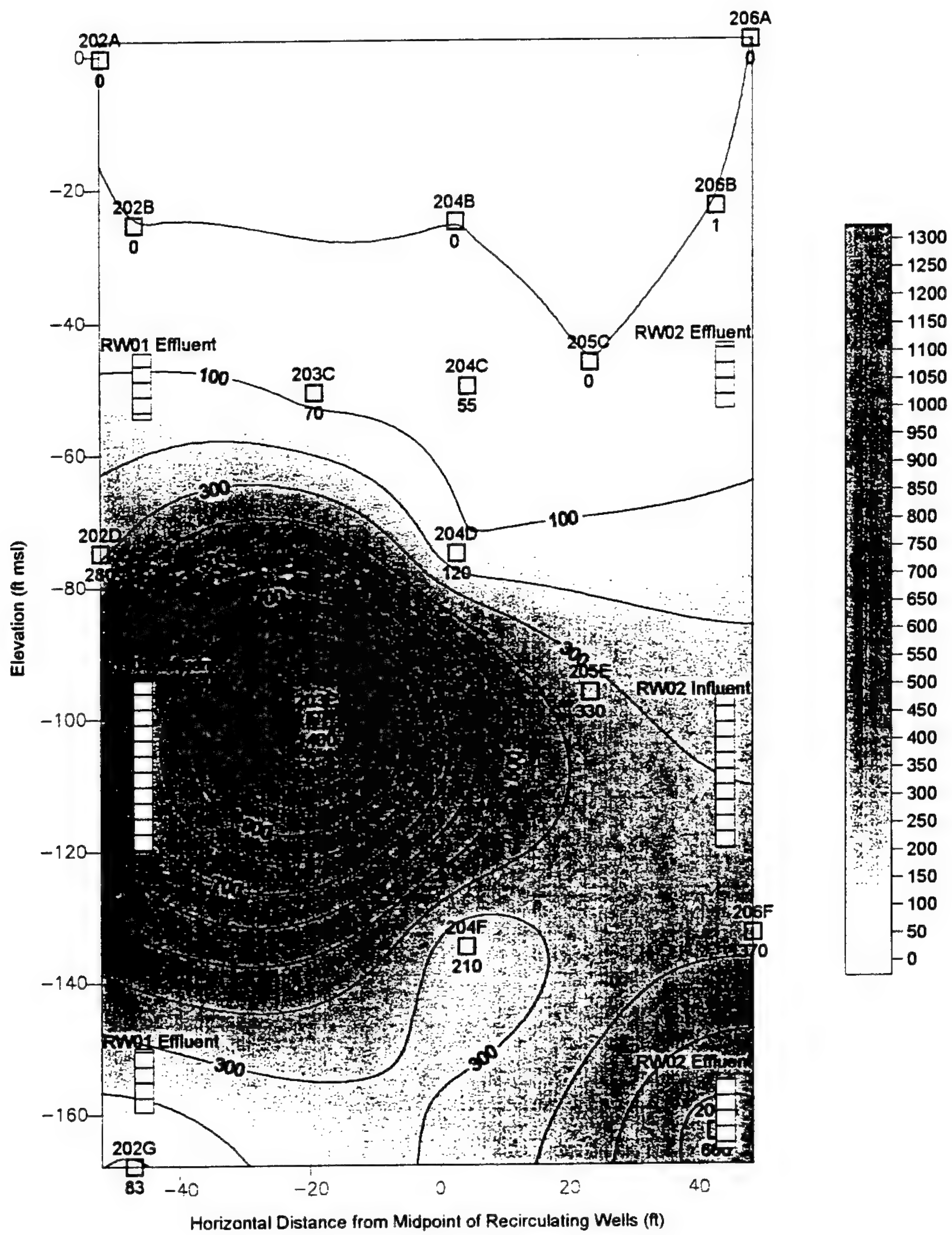
## Recirculating Well Pilot Test: CS-10 No.1

### Section B-B' TCE (ug/L) Round 1



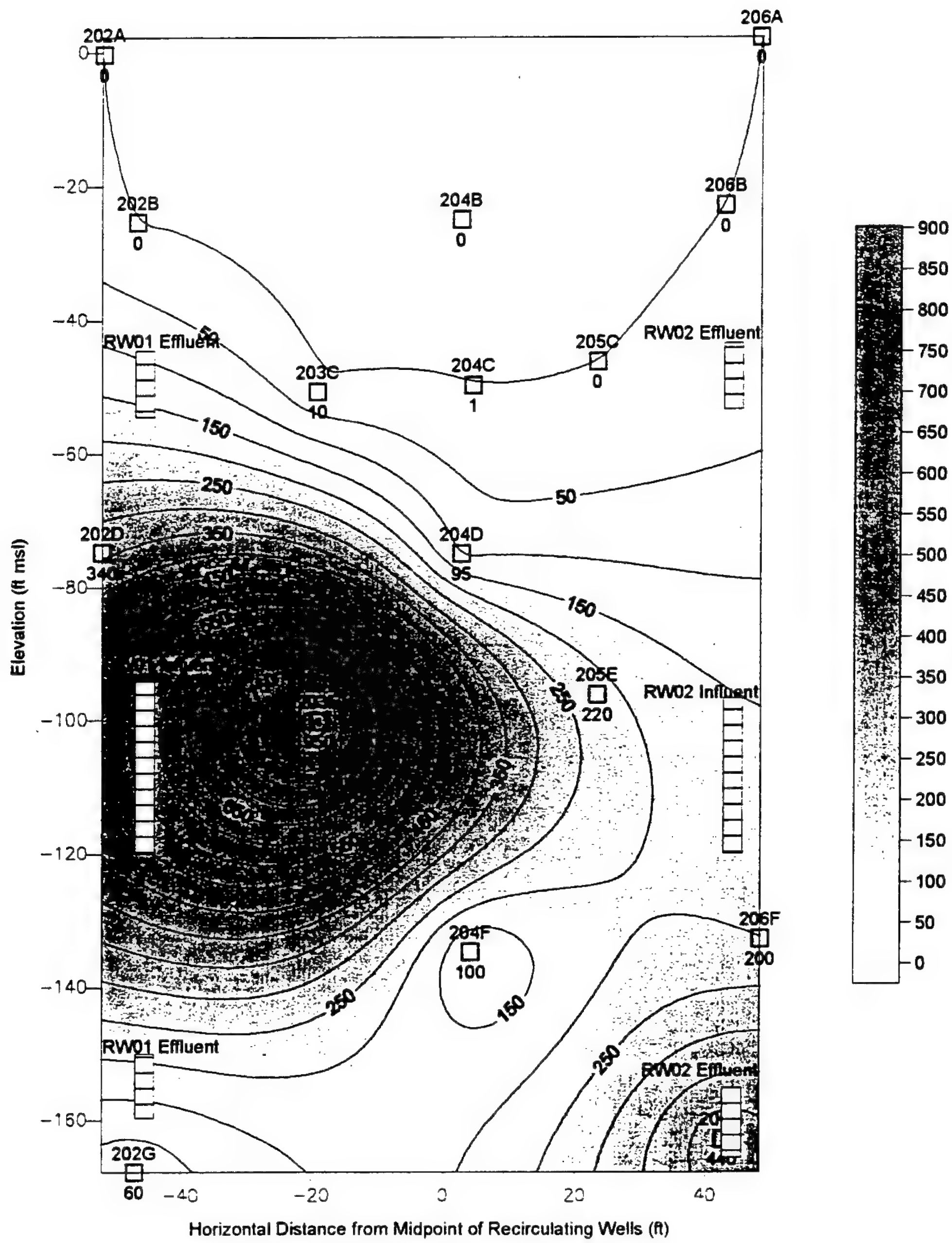
## Recirculating Well Pilot Test: CS-10 No.1

### Section B-B' TCE (ug/L) Round 2



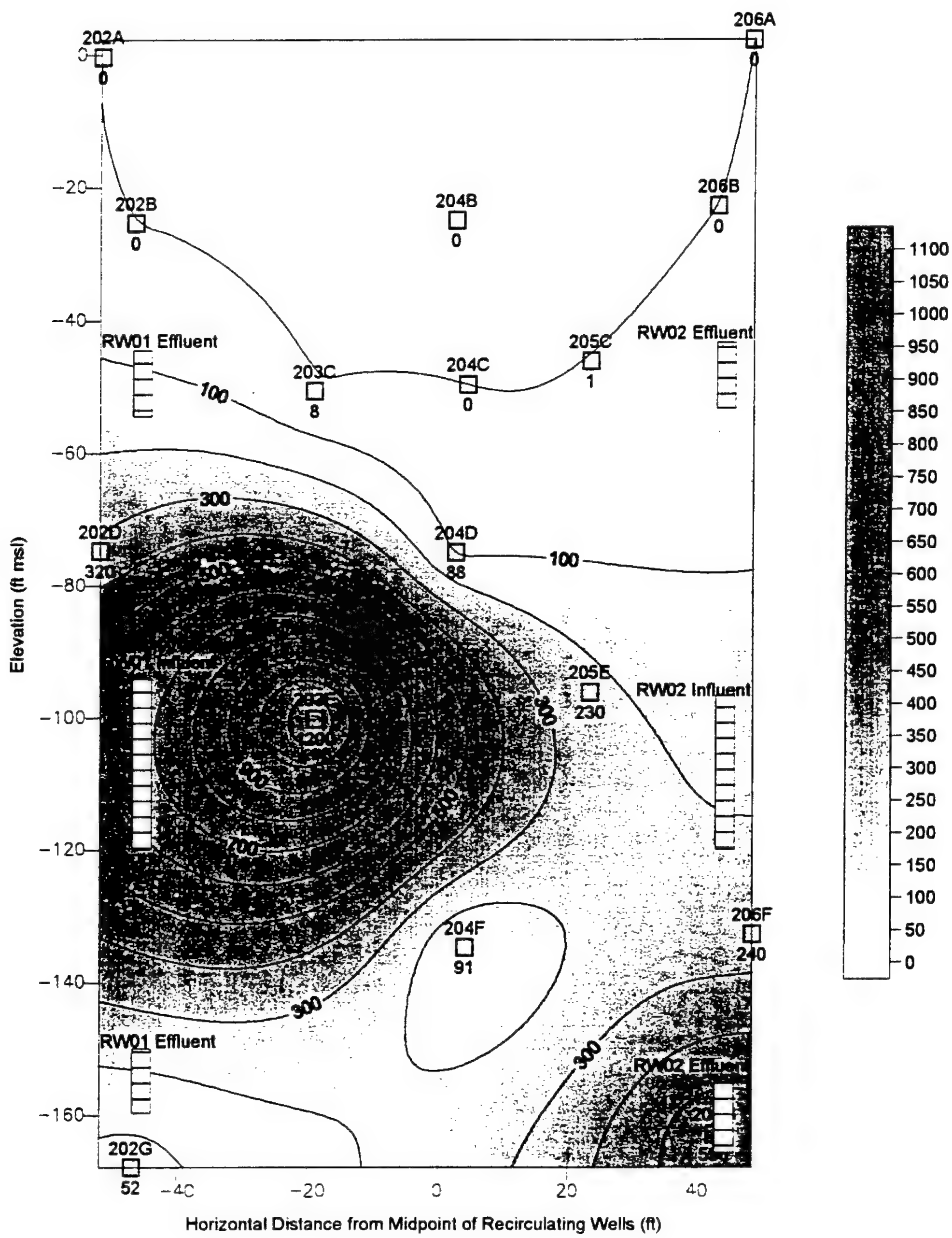
## Recirculating Well Pilot Test: CS-10 No.1

### Section B-B'  TCE (ug/L)  Round 3



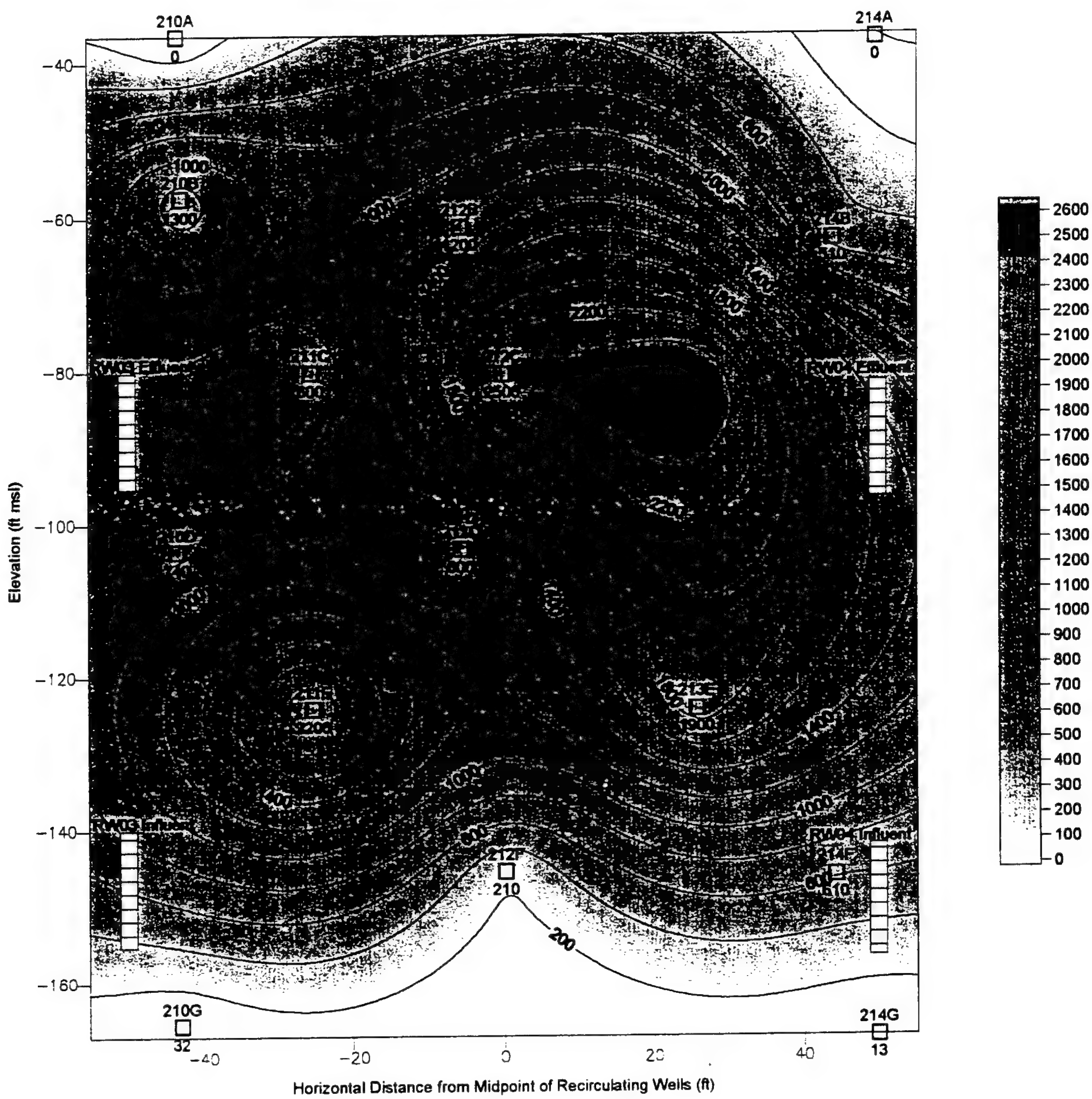
## Recirculating Well Pilot Test: CS-10 No.1

### Section B-B' TCE (ug/L) Round 4



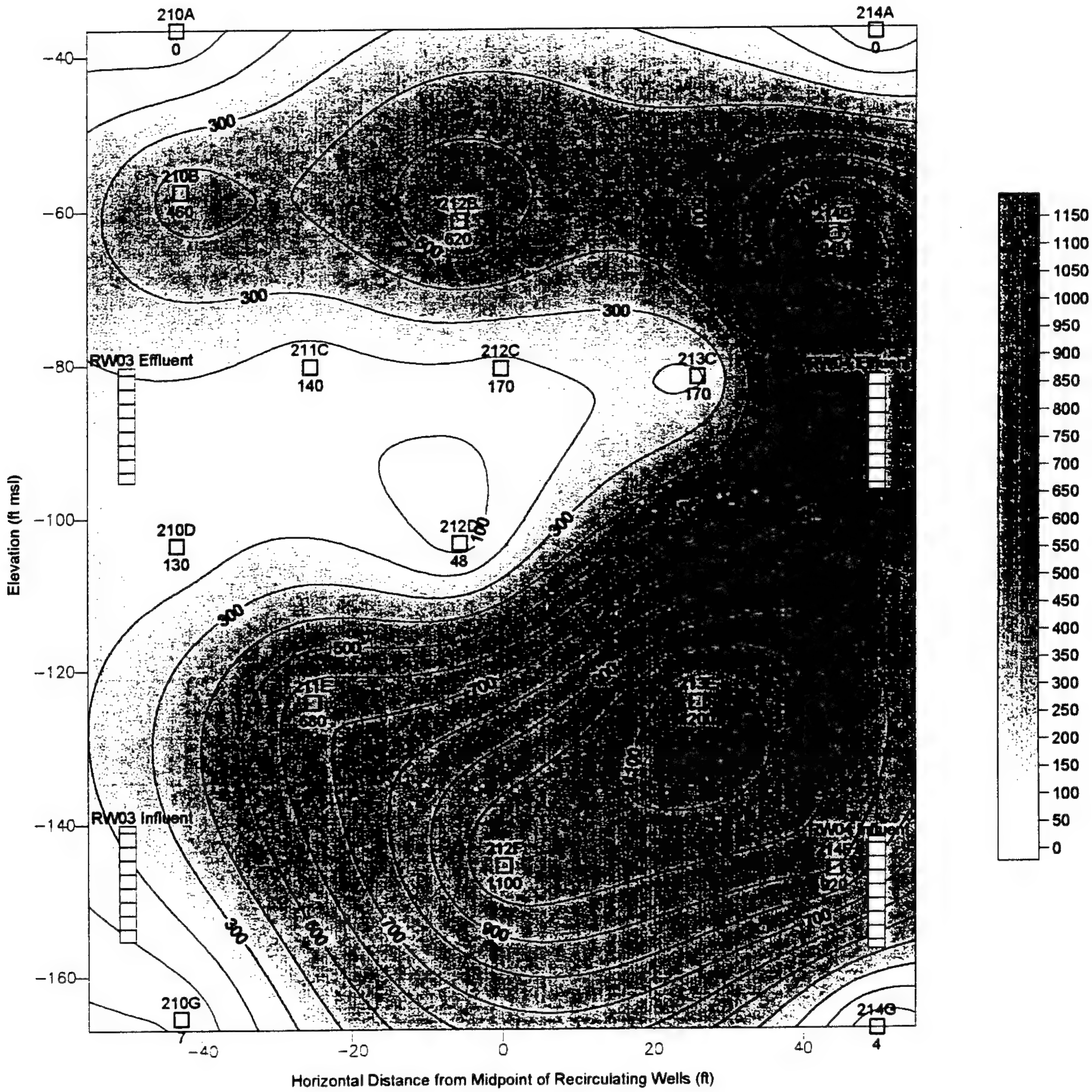
## Recirculating Well Pilot Test: CS-10 No.2

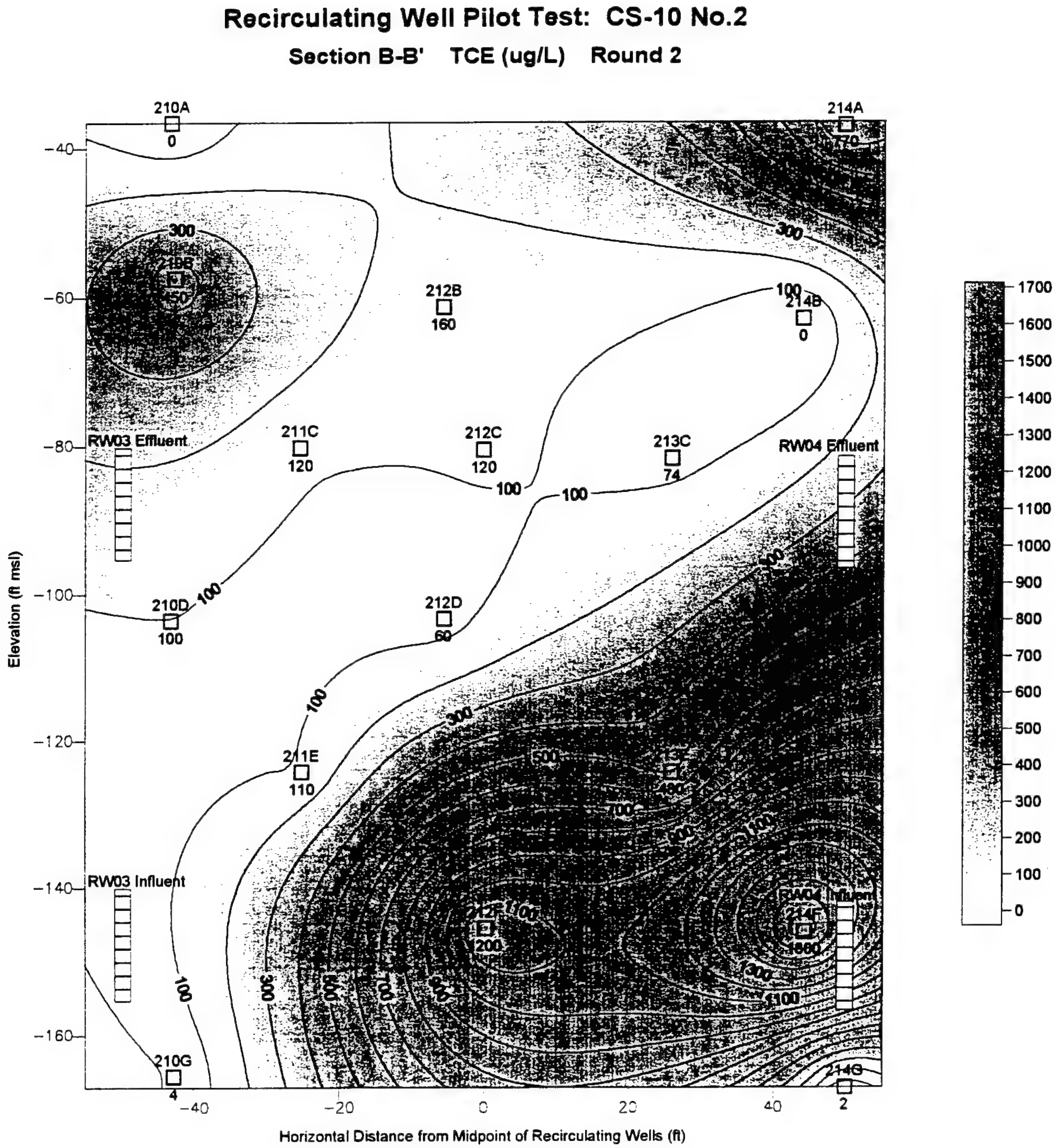
### Section B-B' TCE (ug/L) Baseline



## Recirculating Well Pilot Test: CS-10 No.2

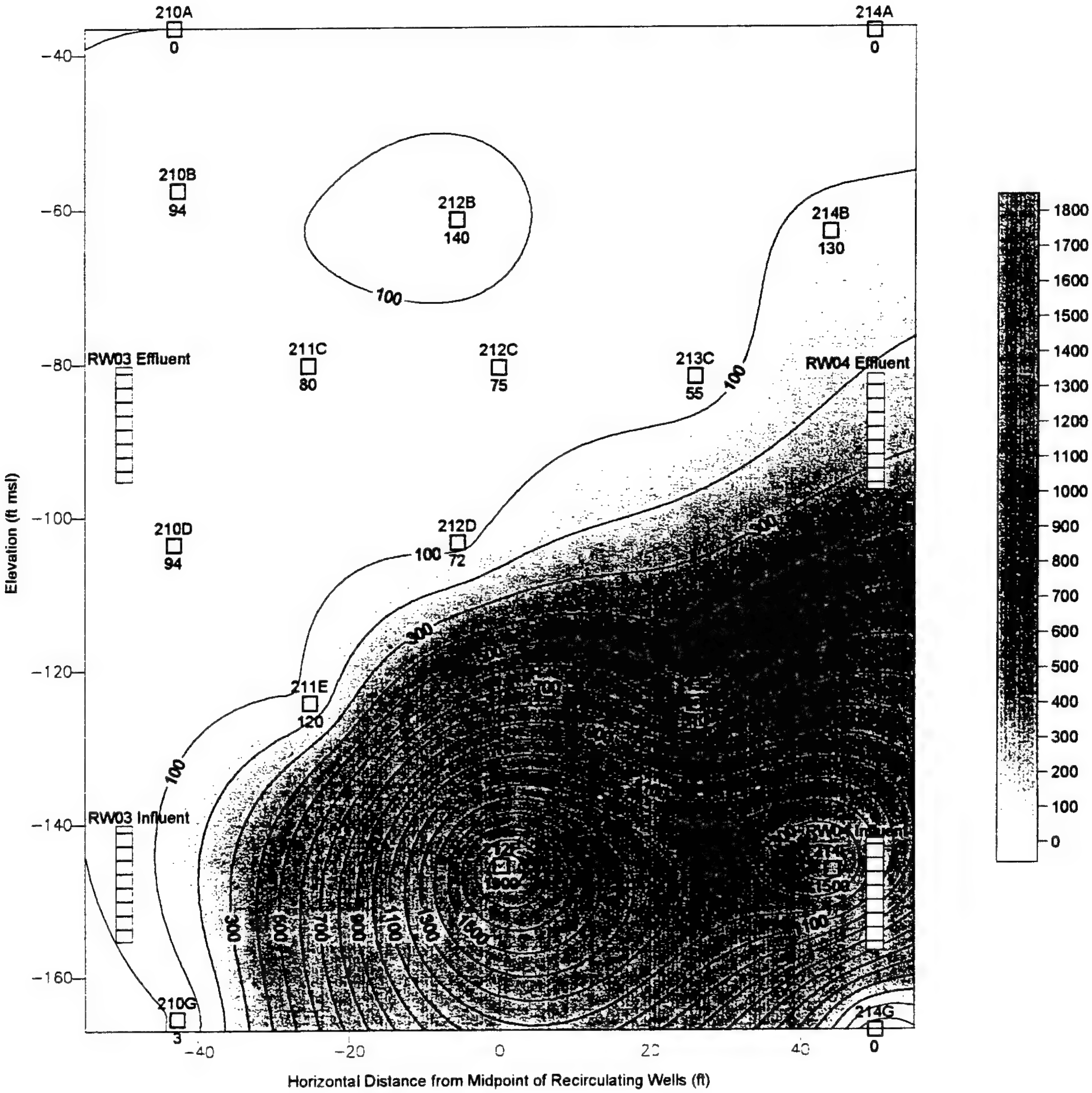
### Section B-B' TCE (ug/L) Round 1




Recirculating Well Pilot Test: CS-10 No.2
Section B-B' TCE (ug/L) Round 2
210A
0
214A
770
210B
450
212B
160
214B
0
211C
120
212C
120
213C
74
RW03 Effluent
RW04 Effluent
210D
100
212D
60
211E
110
RW03 Influent
RW04 Influent
212F
1200
214F
1660
210G
4
214G
2
300
100
500
700
900
1100
1300
Elevation (ft msl)
-40
-60
-80
-100
-120
-140
-160
-20
0
20
40
Horizontal Distance from Midpoint of Recirculating Wells (ft)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

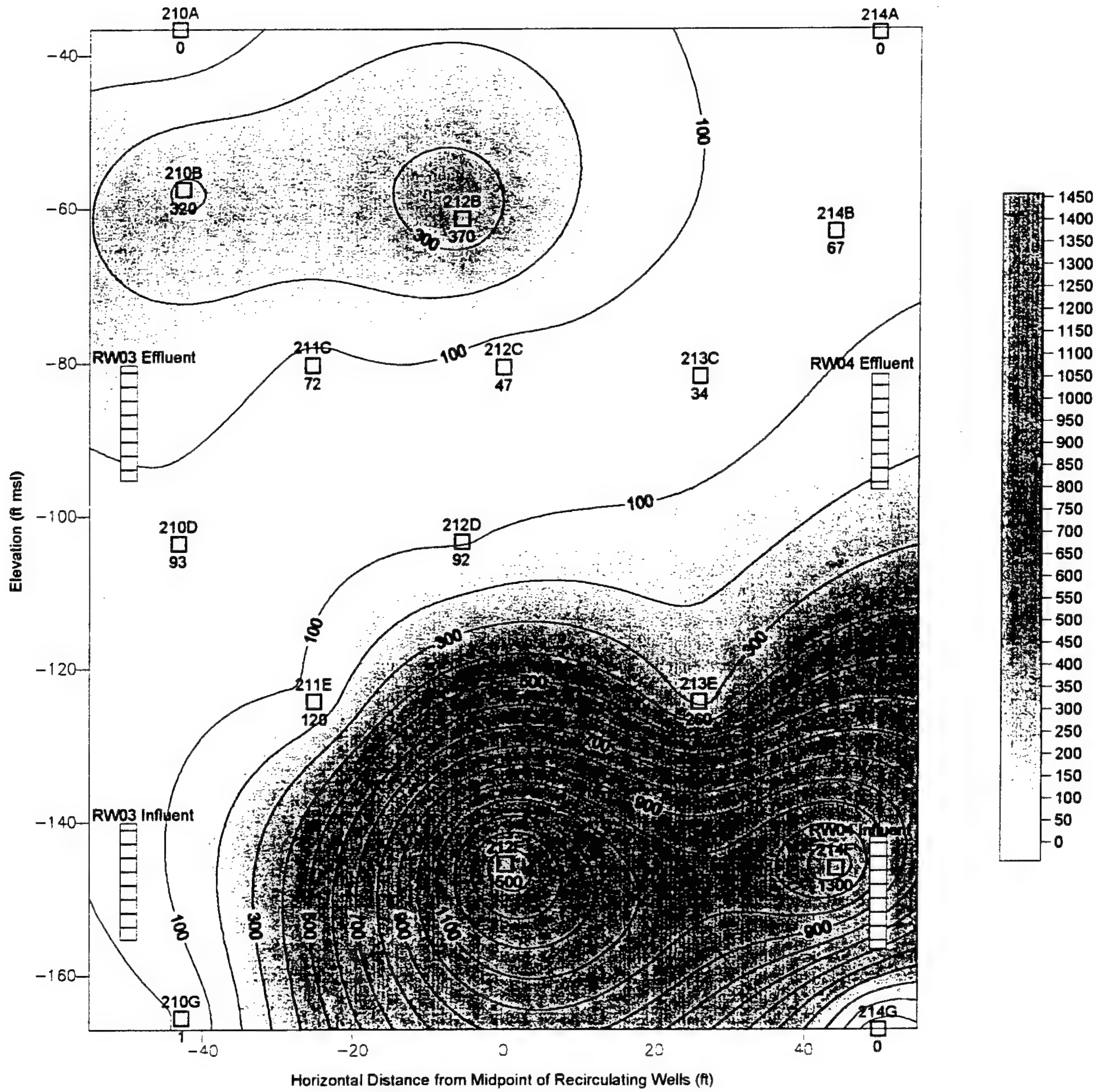
## Recirculating Well Pilot Test: CS-10 No.2

### Section B-B' TCE (ug/L) Round 3



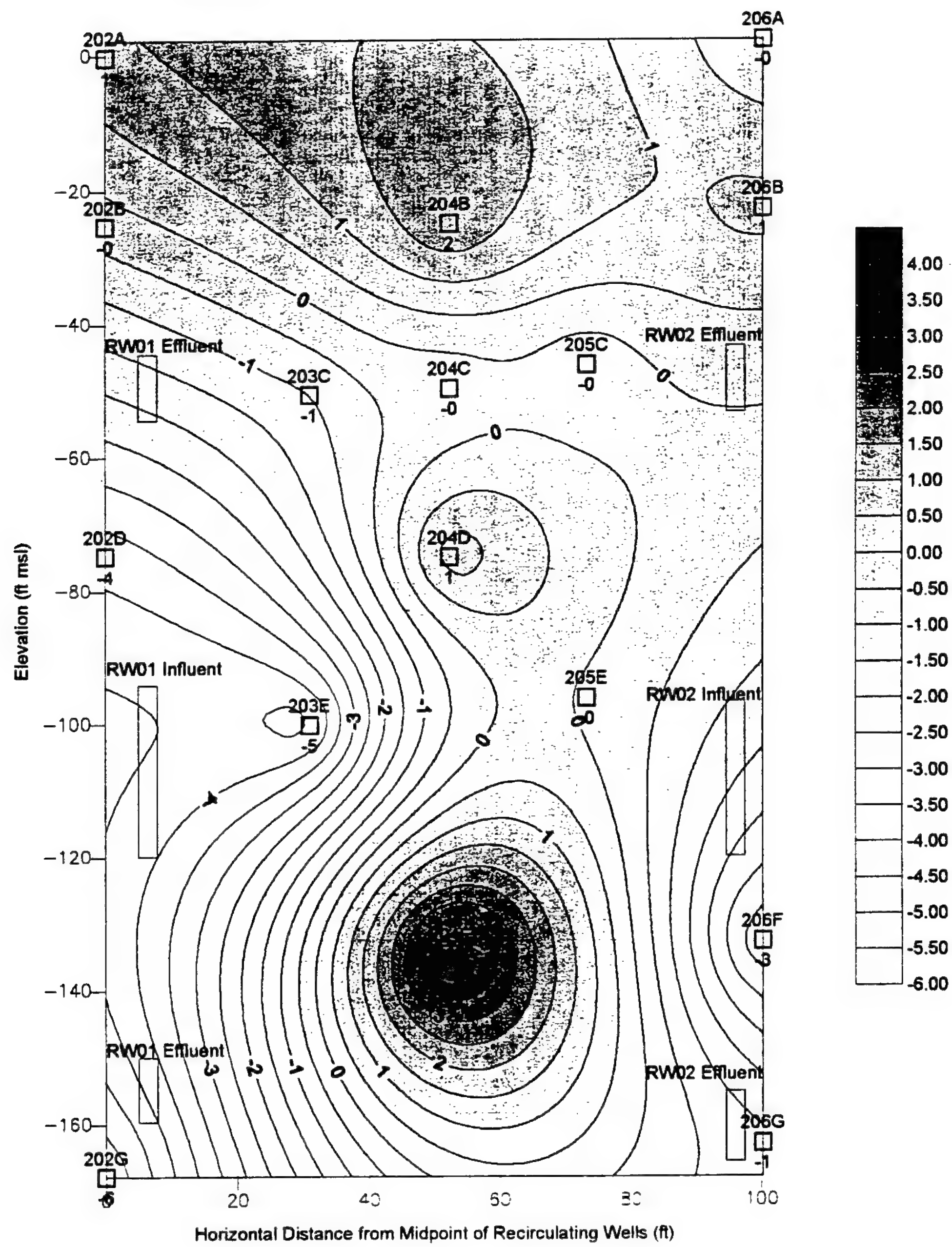
# Recirculating Well Pilot Test: CS-10 No.2

## Section B-B' TCE (ug/L) Round 4



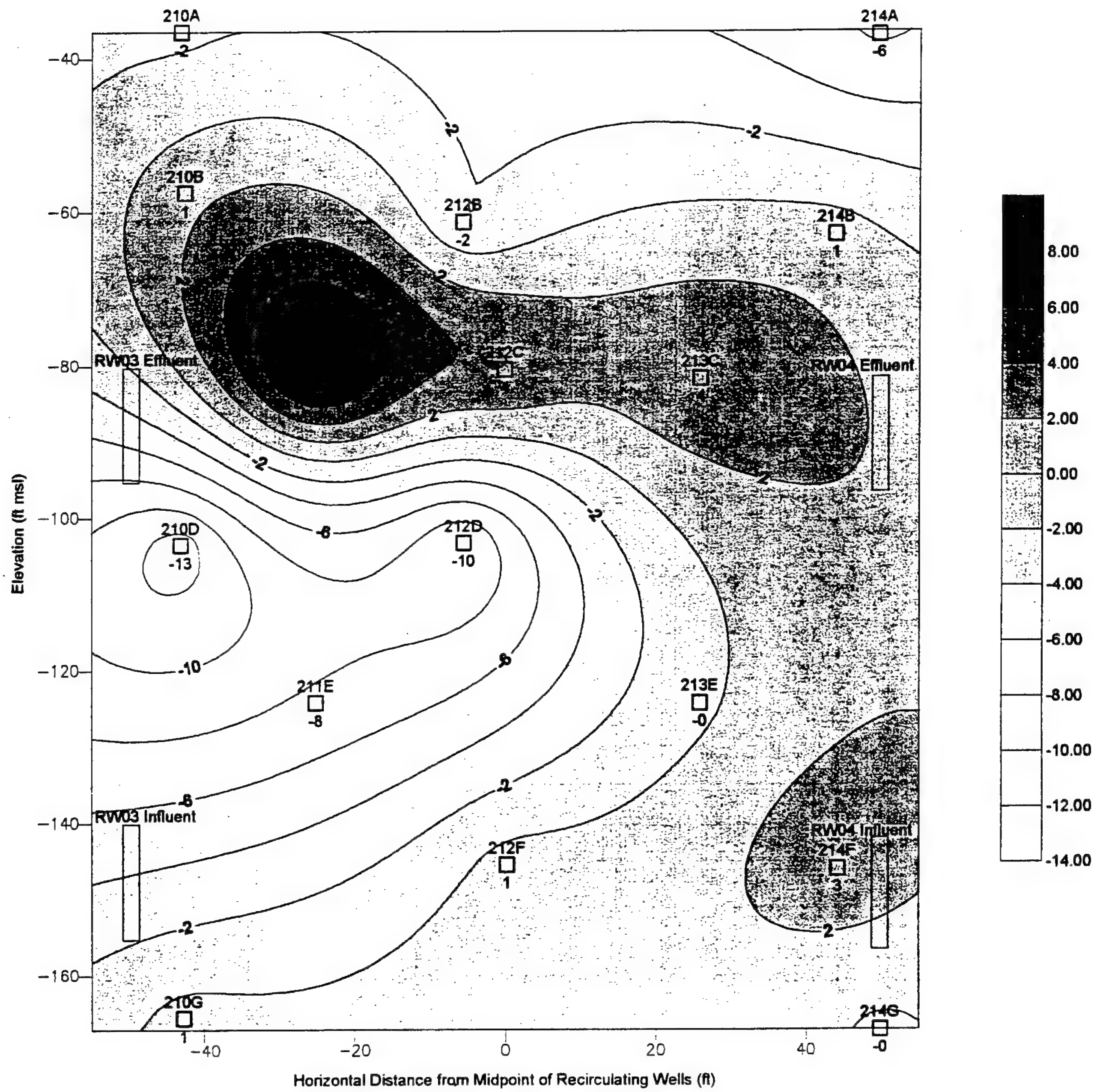
## Recirculating Well Pilot Test: CS-10 No.1

**Section B-B' Change in DO (mg/L) Baseline vs. Round 4**

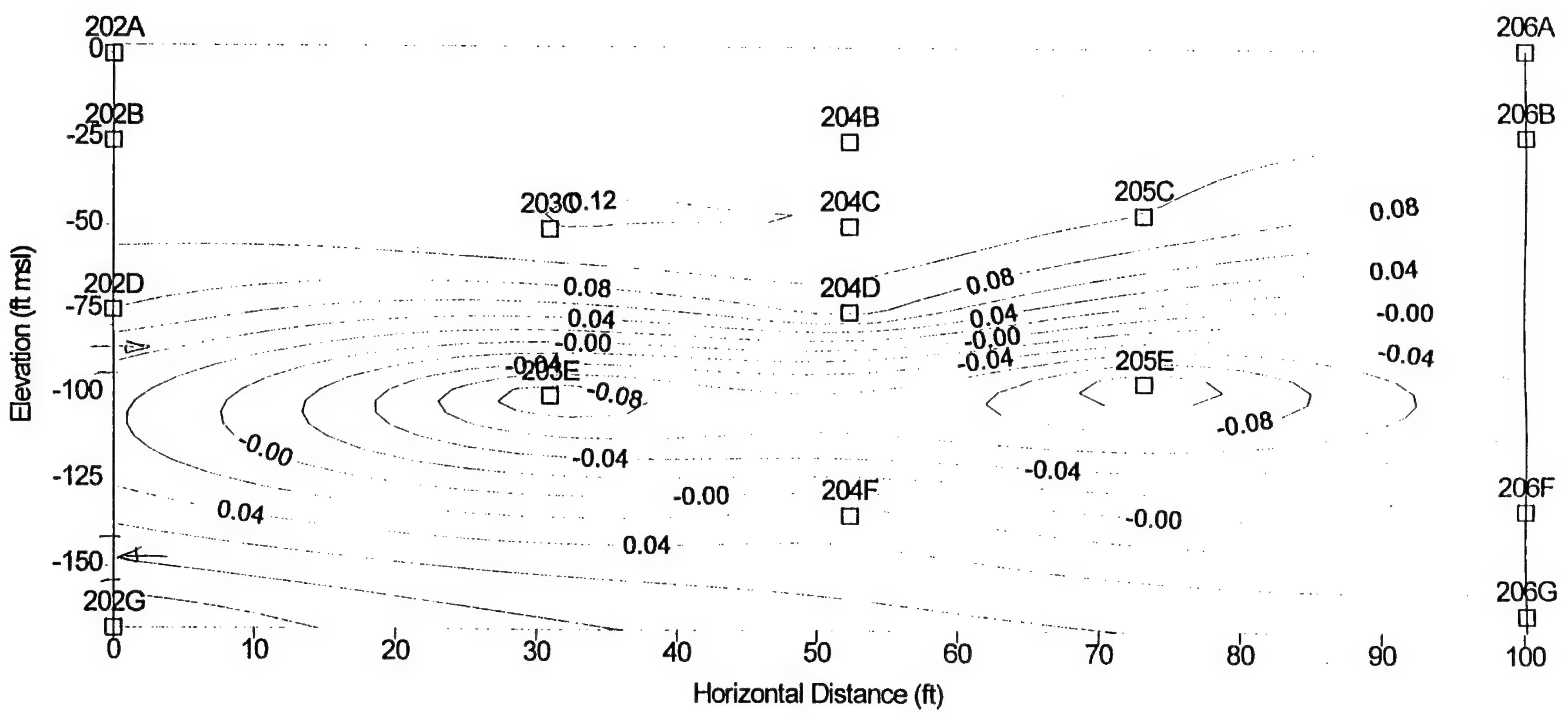


## Recirculating Well Pilot Test: CS-10 No.2

### Section B-B' Change in DO (mg/L) Baseline vs. Round 4

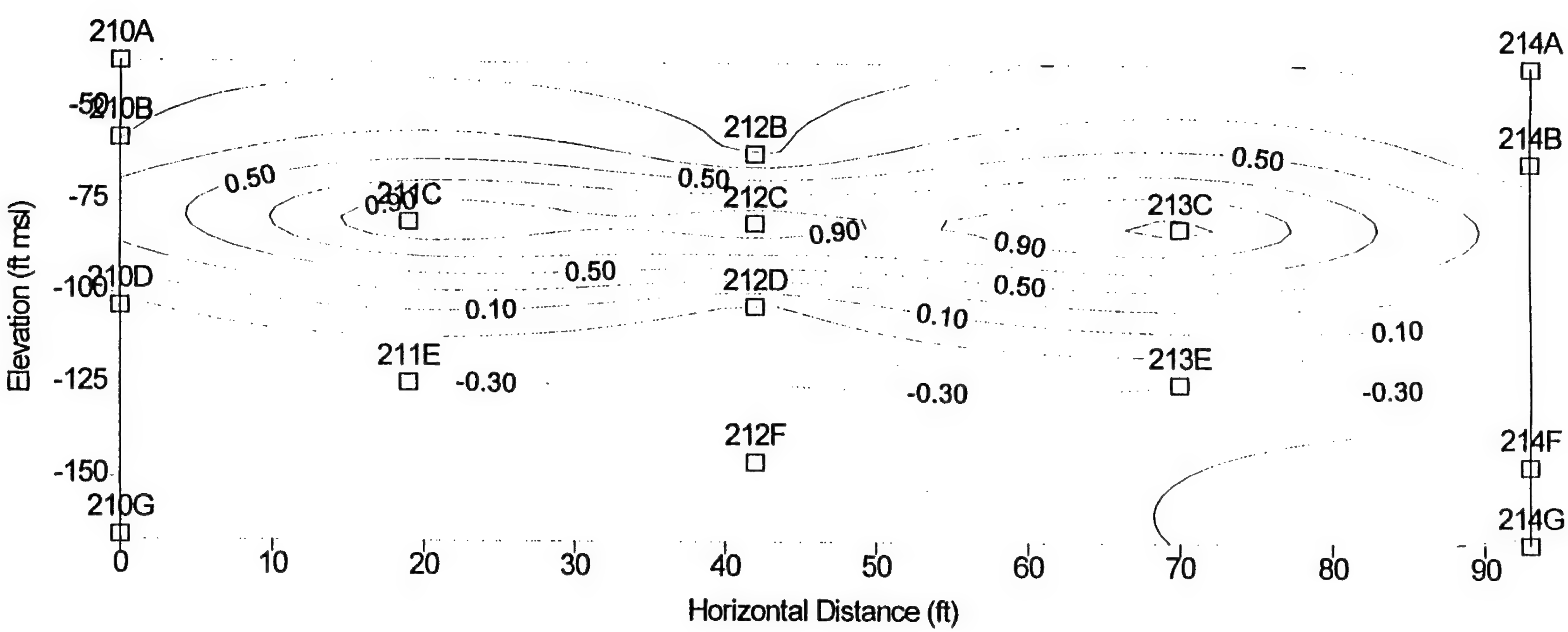


**Recirculating Well Pilot Test: CS-10 No. 1**
**Section B-B' Water Level Changes from Static to Operational**

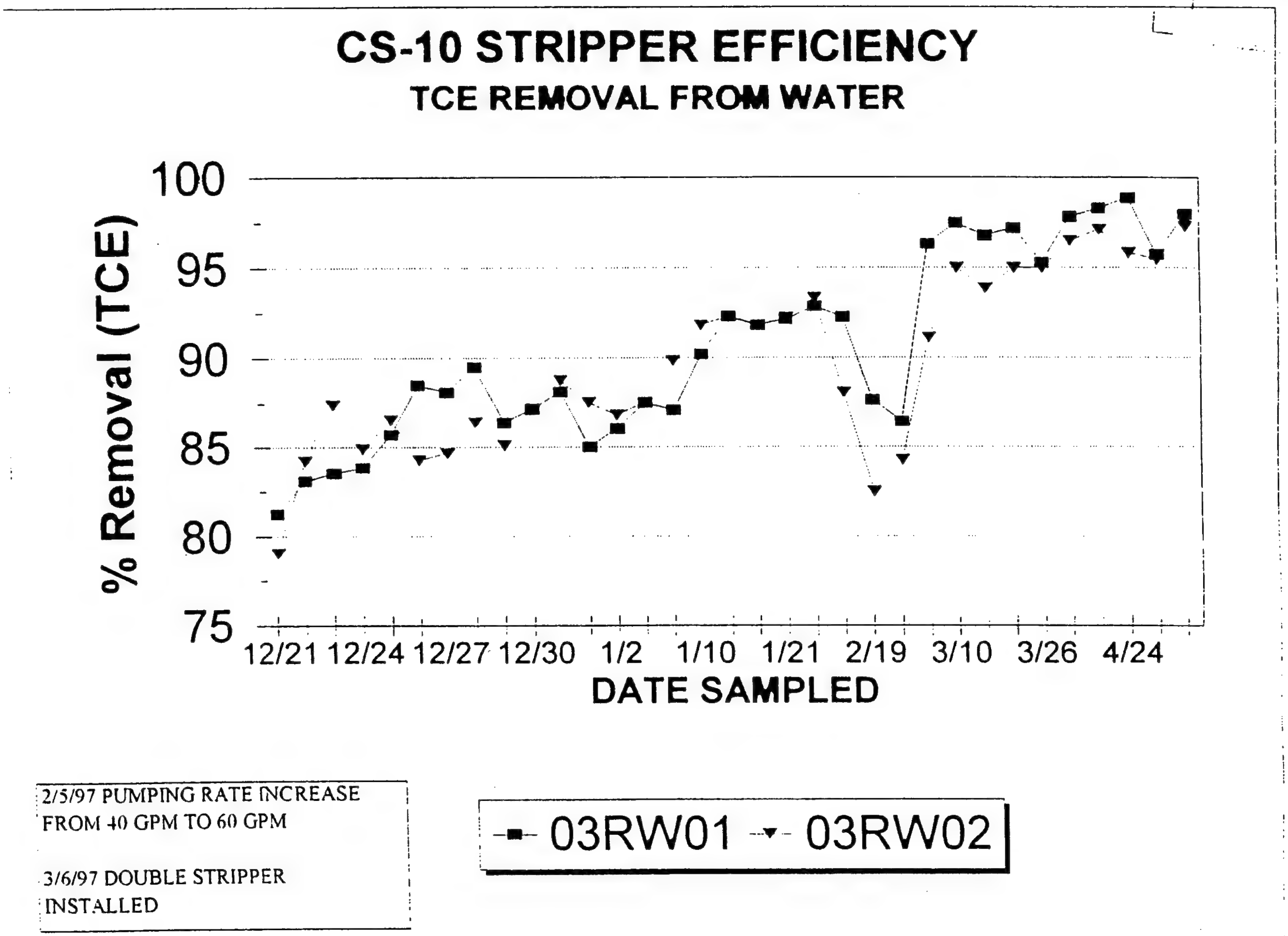


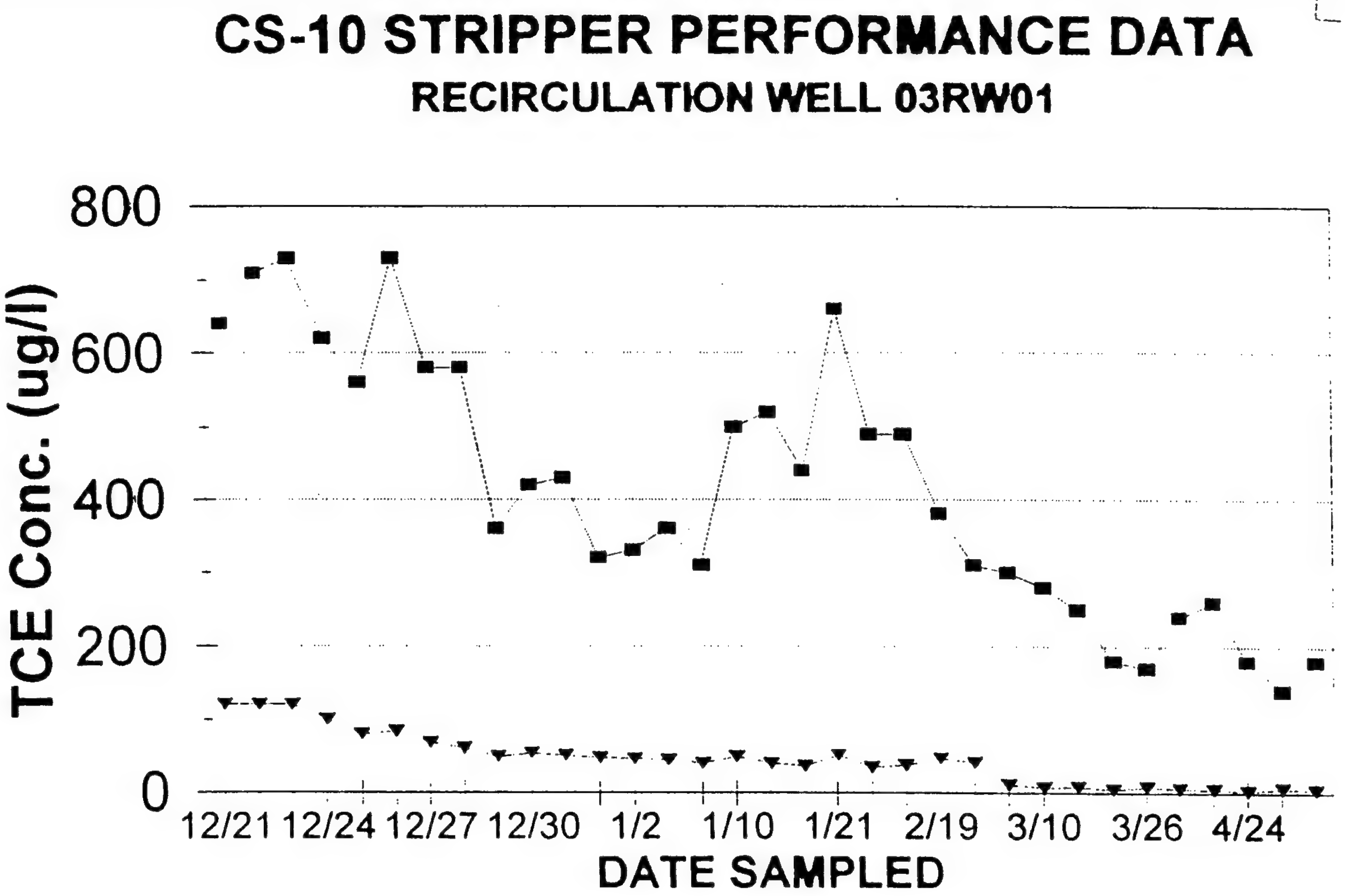

DRAFT

## Recirculating Well Pilot Test: CS-10 No. 2
## Section B-B' Water Level Change - Static to Operational




DRAFT


CS-10 STRIPPER EFFICIENCY
TCE REMOVAL FROM WATER
100
95
90
85
80
75
% Removal (TCE)
12/21 12/24 12/27 12/30 1/2 1/10 1/21 2/19 3/10 3/26 4/24
DATE SAMPLED
2/5/97 PUMPING RATE INCREASE FROM 40 GPM TO 60 GPM
3/6/97 DOUBLE STRIPPER INSTALLED
03RW01
03RW02



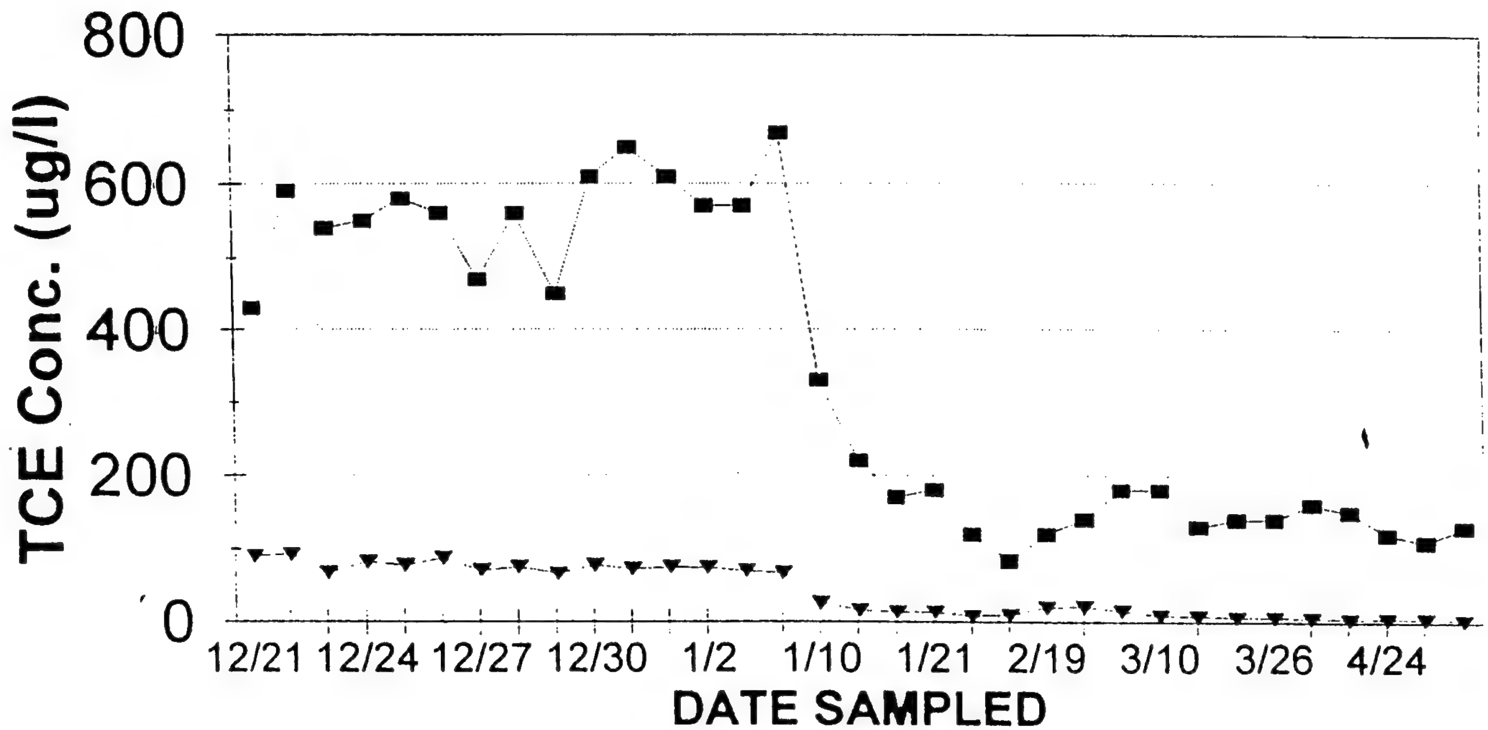

2/5/97 PUMPING RATE INCREASE
FROM 40 GPM TO 60 GPM

3/6/97 DOUBLE STRIPPER
INSTALLED

CONFIDENTIAL

# CS-10 STRIPPER PERFORMANCE DATA

## RECIRCULATION WELL 03RW02



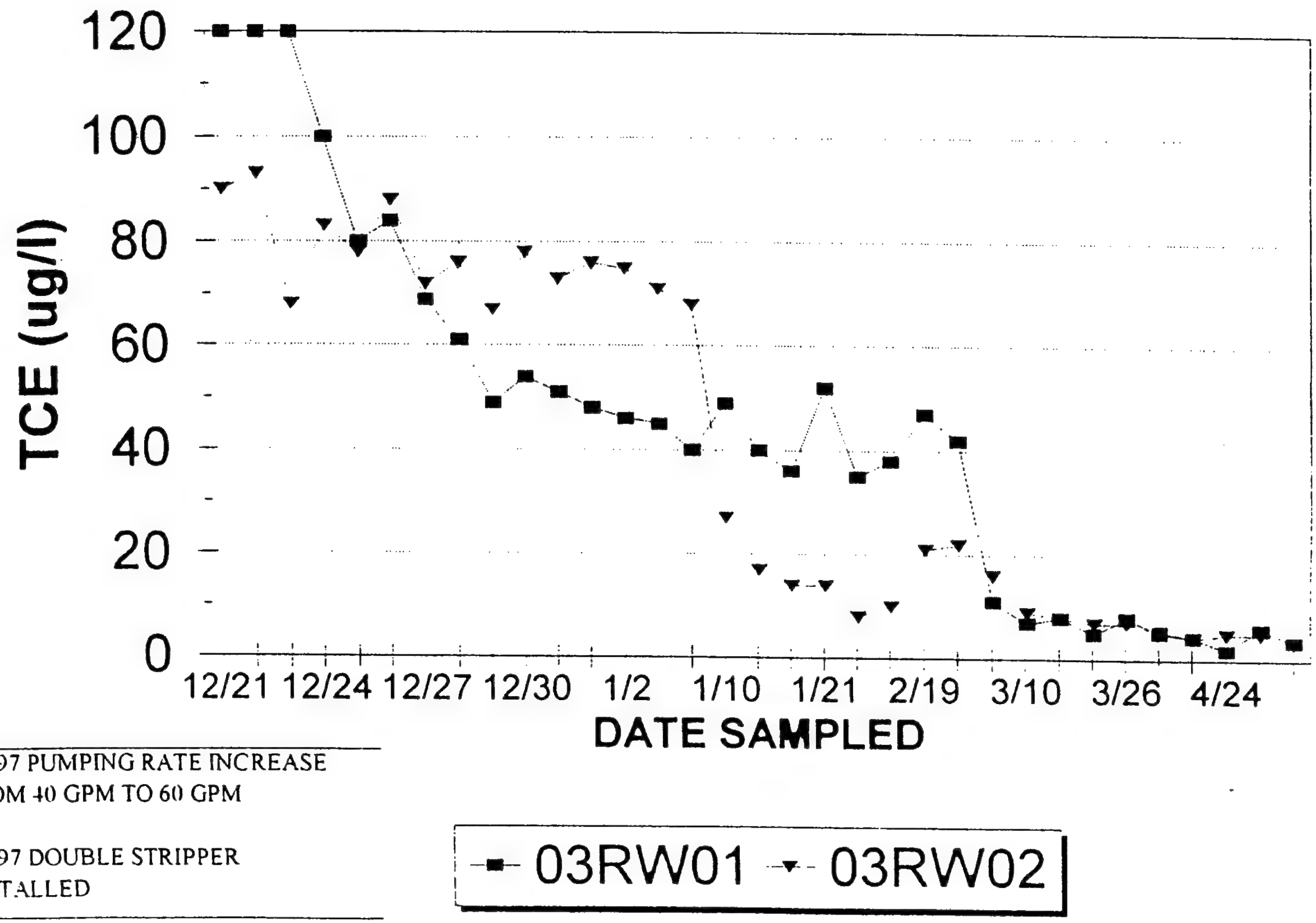

2/5/97 PUMPING RATE INCREASE FROM 40 GPM TO 60 GPM

3/6/97 DOUBLE STRIPPER INSTALLED

Influent  Effluent

CONFIDENTIAL

# CS-10 STRIPPER EFFLUENT CONCENTRATIONS

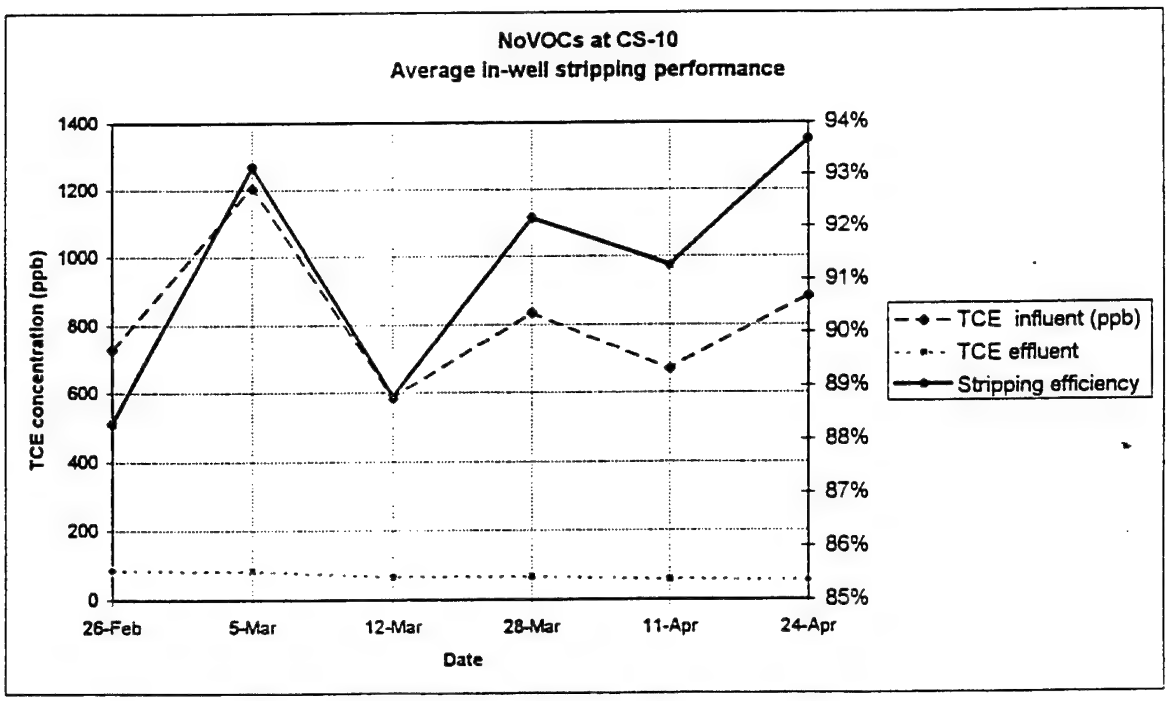



2/5/97 PUMPING RATE INCREASE FROM 40 GPM TO 60 GPM

3/6/97 DOUBLE STRIPPER INSTALLED

# NoVOCs @ CS-10 Preliminary Results In-well performance

| | | 26-Feb | 5-Mar | 12-Mar | 28-Mar | 11-Apr | 24-Apr |
|---|---|---|---|---|---|---|---|
| **Well RW03** | TCE influent (ppb) | 940 | 1700 | 520 | 1100 | 960 | 1200 |
| | TCE effluent | 110 | 100 | 78 | 84 | 73 | 69 |
| | **Stripping efficiency** | **88%** | **94%** | **85%** | **92%** | **92%** | **94%** |
| | [Fe] influent (ppm) | | | 0.23 | | | |
| | [Fe] effluent | | | <0.1 | | | |
| | [Mn] influent (ppm) | | | <.02 | | | |
| | [Mn] effluent | | | <.02 | | | |
| | | 26-Feb | 5-Mar | 12-Mar | 28-Mar | 11-Apr | 24-Apr |
| **Well RW04** | TCE influent (ppb) | 520 | 710 | 650 | 570 | 380 | 570 |
| | TCE effluent | 61 | 65 | 53 | 47 | 44 | 43 |
| | **Stripping efficiency** | **88%** | **91%** | **92%** | **92%** | **88%** | **92%** |
| | [Fe] influent (ppm) | | | <0.1 | | | |
| | [Fe] effluent | | | <0.1 | | | |
| | [Mn] influent (ppm) | | | <.02 | | | |
| | [Mn] effluent | | | <.02 | | | |
| | | 26-Feb | 5-Mar | 12-Mar | 28-Mar | 11-Apr | 24-Apr |
| **AVERAGE** | TCE influent (ppb) | 730 | 1205 | 585 | 835 | 670 | 885 |
| | TCE effluent | 85.5 | 82.5 | 65.5 | 65.5 | 58.5 | 56 |
| | **Stripping efficiency** | **88%** | **93%** | **89%** | **92%** | **91%** | **94%** |



## 3.0 PILOT STUDY EVALUATION

The intent of the pilot test program is to collect the data required to adequately understand the effectiveness of GCW technology. If the technology is shown to meet the intended goals and requirements at MMR, then GCW technology could be selected for use as part of a remedial alternative. Since the technology is an in-situ technology and requires establishing a circulation cell in groundwater, there are uncertainties regarding the overall performance. Thus, a pilot program was deemed appropriate, prior to full-scale operation, in order to determine the effect that site specific factors such as aquifer anisotropy and aquifer thickness would have on the performance of this technology. Additionally, since this technology is offered by more than one vendor, it was determined that multiple vendors should be evaluated during the pilot program.

GCW technology includes aspects that can be measured and controlled, i.e. pumping rates, screen depths, applied vacuum, etc., and aspects that cannot be easily measured or controlled, i.e. the extent of the circulation cell and the amount of circulation. This evaluation has been based upon the data collected during the pilot program through early May, 1997, and preliminary interpretations of that data. This includes system operational data, groundwater quality data, and piezometeric head data. Since the pilot program is an ongoing program, and additional data collection efforts are continuing, the database is not as complete as it will be. Interpretive work is also ongoing, and substantial additional modeling is planned.

This section reviews the available pilot test data and provides a discussion of the information. The evaluation program was performed in two phases. The first phase of the evaluation involved compiling the available pilot test data and submitting this information to the panel members prior to attending a week long meeting at MMR. The goal of providing the data package to the panel members prior to the evaluation meeting was to facilitate the review process. Following a brief period for data review, the panel convened at the MMR facility during the week of May 19th, 1997, where additional information was presented by the on-site contractor and the GCW technology vendors who are subcontractors to the on-site contractor. Presentations were intended to provide the contractor and the vendors an opportunity to discuss the progress of the pilot testing program, identify their evaluation of the current data, and highlight any aspect of the technology that they felt should be noted. The meeting also provided the panel with an opportunity to visit each pilot demonstration site and inspect the archived soil samples that were collected during the installation of the monitoring wells. The evaluation focused primarily on the data that was collected for the CS-10 location only, as these systems are installed in more contaminated groundwater, making data interpretation more feasible.

## 3.1 GROUNDWATER HYDRAULICS

For GCW technology to be effective, a circulation cell must be established, involving the vertical movement of groundwater from a discharge screen or screens to an intake screen or screens. There are two reasons for establishing a circulation cell. One is to enhance vertical flow increasing removal of Non-Aqueous Phase Liquids (NAPL) or sorbed materials. This is important for application to known source zones where high concentrations, i.e. thousands of mg/kg, are known to exist in soils. The second reason is to have multiple passes of water through the treatment process, in this case air stripping, to improve treatment efficiency. Groundwater is captured, treated and discharged, in-situ, from the circulation well. A portion of this released water is then recaptured and treated again to improve overall system treatment efficiencies. Retreatment may be required because the in-well, co-current stripping process is less efficient than what could be attained with an above ground counter-current air strippers. At high air to water ratios, in-well air strippers can achieve stripping efficiencies in excess of 90%, however, greater reductions may be required to achieve the target treatment goals. The panel noted that for purposes of plume capture, it is not necessary to create a circulation cell. Plume capture can be accomplished if all upgradient contaminated groundwater is captured, treated to the required levels and discharged, without the need for recapture. This can be accomplished by utilizing the same well design as a circulation well. However, instead of treating the water in-situ, higher efficiency air stripping can be attained with aboveground strippers. The process becomes a simple pump and treat system, not GCW technology.

It is important to point out that the panel agrees that vertical flow maybe desirable in a stratified system where high concentrations of contaminants are bound, usually in a NAPL plume, in low permeability layers of the aquifer. This level of contamination is found in highly contaminated source zones where soil concentrations exceed 1000 mg/kg. Horizontal flow, as is typical of a conventional pump and treat approach to groundwater remediation, can by-pass this contamination. Vertical flow can force groundwater through these layers resulting in increased dissolution and mass removal. Neither the CS-10 nor Ashumet Valley sites have concentrations that would suggest such bound contamination are present. It should also be pointed out that, based on data reviewed by the panel, it was agreed that no such contaminated location could be identified at MMR. The sole technical benefit of vertical circulation at MMR appears to be treatment goal attainment via multiple pass treatment.

In order to achieve a low target concentration level, circulation wells require multiple treatment passes. Contaminated water is drawn into the circulation well at the intake screen, usually at the bottom of the circulation cell. In the case of the UVB installation at CS-10, the intake is at an intermediate depth. After treatment within the well, the flow is released from the discharge screen,

usually at the top of the circulation cell. In the case of the UVB installation at CS-10, water is discharged at the top and bottom of the contaminated aquifer. The piezometeric head at the discharge screen is increased due to the release of water. A portion of the water that is released from the well is recaptured by the circulation cell and retreated in the well. Some treated water is not recaptured and released from the circulation cell, usually at the top of the discharge zone, away from the influence of the intake well screen. The concentration of TCE within the circulation cell should decrease to a point where quasi-equilibrium is reached between the higher concentrations near the intake zone and the lower concentrations at the discharge zone. These should remain relatively constant, providing all other variables, such as treatment efficiency, are constant. As a portion of the treated water will be recycled, a question arises as to how much of this water is allowed to escape and how much is recaptured. This is not an issue with a typical extraction, treatment and reinjection (ETR) system as a target concentration treatment level is achieved in one pass.

Proving that a circulation cell has formed is difficult, as the entire process occurs over a hundred of feet below the ground surface. For this pilot study, pressure and concentration data were collected at several discrete aquifer monitoring locations and depths within the expected circulation zone. These data were presented, showing that a vertical hydraulic gradient had been created. However, the panel felt that this alone was insufficient evidence to prove or disprove that a circulation cell has developed. For vertical flow to occur, the vertical hydraulic gradient must be sufficient to move groundwater through whatever low permeability zones may be present due to aquifer anisotropy. In order to determine wether the vertical gradients are sufficient to move water vertically, thereby supporting the contention that circulation cells were present, the vendors rely on modeling. In order for modeling to accurately depict the conditions in the aquifer, the vertical permeability of the aquifer must be known with a high degree of confidence. It was the opinion of the panel that, at MMR, an adequate understanding of the vertical permeability does not exist, and may not be practical to obtain to support this modeling.

One vendor, NoVOCs, suggested representing circulation as the ratio of the pumping flow in the circulation well, $Q_{well}$, to the flow of water that moves into and out the circulation cell, $Q_{flux}$.

$$N = (Q_{well}/Q_{flux}) - 1$$

where:

$N$ = the circulation factor, unitless,

$Q_{well}$ = the pumping flow in the circulation well, gallons per minute (gpm),

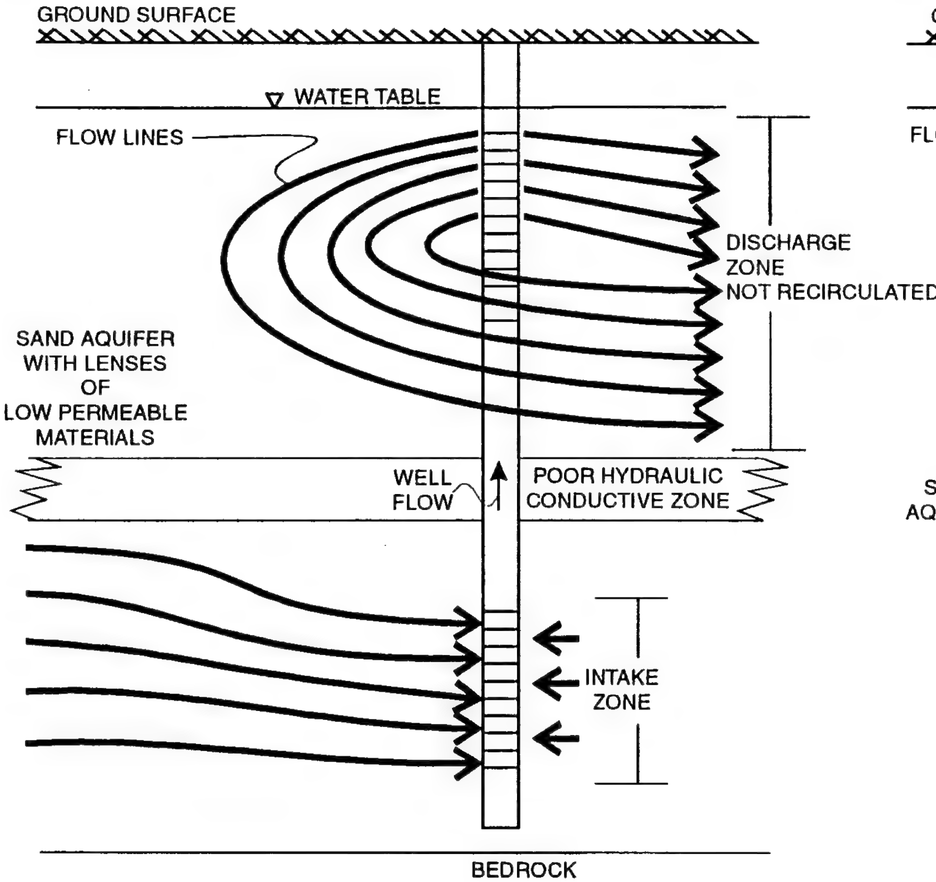
$Q_{flux}$ = the flow entering and leaving the circulation cell, gallons per minute (gpm),

Conditions where there is no circulation are represented as N = 0. Values of N that are greater than zero represent conditions where circulation is occurring. The larger the value of N is, the greater the amount of groundwater that would be circulated. Large values of N suggest that only a small amount of flow is released from the circulation cell. If N is extremely large, then the water in the cell is continually recycled and virtually no water is released. If the concentration of the treated water is too high due to low stripping effectiveness and N is not large enough to circulate and retreat this water, then the concentration of groundwater that is released past the circulation cell could be above a target value.

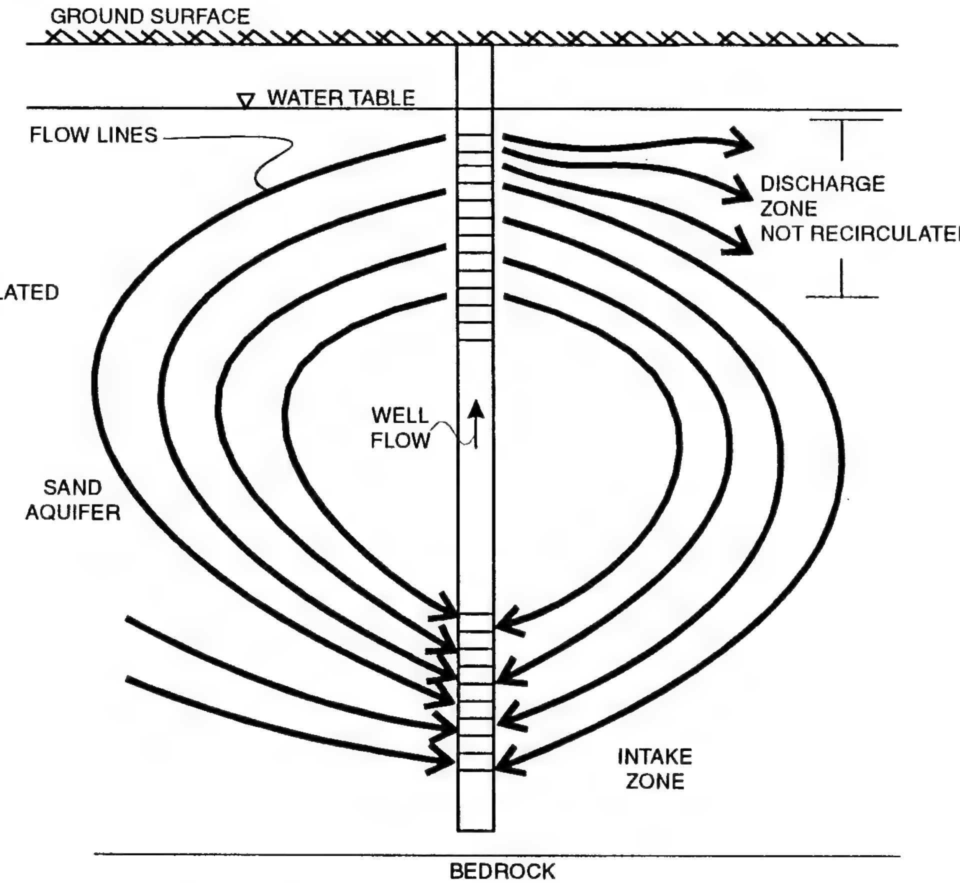
Both vendors rely on groundwater modeling to determine the value of N. The UVB vendor indicated that approximately 50% of the flow is circulated, i.e. N equals 1. The NoVOCs vendor indicated that circulation was higher suggesting that for their system N was probably between 2 or 3.

The pilot study piezometeric data and the concentration changes in various wells were evaluated to determine if a circulation cell did exist. If the circulation cell did exist, then determining the extent of the circulation cell was of interest. The panel believed that neither the zone of capture nor the existence of a circulation cell could be proven with the existing data for any of the three demonstration sites. In presenting the data, both of the technology vendors believed that circulation flow was occurring, based upon the pressure data and observed changes in concentration. Groundwater modeling was used by the vendors to supplement this information and served as the basis for estimating the extent of circulation. Although the panel agreed that some of the data were consistent with development of a circulation cell, the same data were also consistent with an alternative hypothesis that no circulation cell had formed. The following figure provides an indication of the two possible occurrences. The panel agreed that if the circulation cells are closed, they very likely are not circulating at the design rate because the influent concentration appears to be on the order of twice as high as what would be expected if sufficient circulation was occurring. In order to achieve the target goal of MCLs, the system at the CS-10 location may require multiple circulation due to the low stripping efficiency. The figure provided on the following page depicts two possible cases that may be occurring at the circulation well sites at MMR. Case 1 depicts a condition where no circulation is occurring. Case 2 shows the system in operation as designed with multiple passes. With the current data, the panel could not determine which of these two cases were occurring. It is also possible that actual site conditions are somewhere in between the two cases illustrated in the figure.

If circulation is occurring, then the influent concentration of TCE at the circulation well is expected to decline over time as mass is removed. The panel considered the available data and concluded that the data did not strongly support circulation was occurring. This could be because the circulation




CASE 1
RECIRCULATION IN
ANISOTROPIC AQUIFER




CASE 2
RECIRCULATION IN
ISOTROPIC AQUIFER

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

CLIENT/PROJECT TITLE
MASSACHUSETTS MILITARY RESERVATION
RECIRCULATION WELL TECHNOLOGY
EVALUATION

DEPT. ENVIRONMENTAL ENGINEERING | DWG NO 731475-01000

CONDITIONS INFLUENCING
ESTABLISHING RECIRCULATION

SCALE NA | DATE JUNE 1997

GRAPHICS\MMRCASE.CDR

cells had not yet closed, but will eventually close. However, it is also possible that the circulation cells do not exist.

Although some variations in the influent concentrations for the UVB systems at the CS-10 North location were noted, there was an apparent decrease in the influent concentrations measured within the circulation wells, 03RW0001 and 03RW0002, prior to in-well treatment. The initial influent concentrations for both the UVB wells at the CS-10 locations were approximately 600 ug/L in late December 1996. This decreased to approximately 180 ug/L in late April, 1997. This data appears to be consistent with what would be expected if circulation were occurring. However, the upgradient concentration, represented by monitoring well, MW0201, also decreased from an initial concentration of approximately 400 ug/L to about 150 ug/L at the F level. A change was also observed at the E level but was not as substantial. This change could be responsible for at least some of the observed drop in influent concentration at both the UVB circulation wells at CS-10. This decline in influent treatment concentration is commonly seen in one pass groundwater extraction and treatment systems. Alternatively, the drop in influent concentration may be due to the movement of cleaner water into the intake screens as water is circulated. Greater influent decreases may occur in the future as more time may be required for the complete circulation cell to fully develop. On the other hand, it is also possible that the cell simply does not exist.

Unfortunately, at the NoVOCs site, located at the CS-10 South location, the initial two months of influent concentrations for the two circulation wells, 03RW0003 and 03RW0004, were not collected, making an evaluation of change in concentrations difficult. Influent TCE concentrations were available from weekly sampling from February 26, 1997 through April 24, 1997. The data suggests that the concentration of groundwater flowing to the circulation wells remained constant over the February to April sampling period. For example, the initial influent concentration of TCE measured on February 26 at the circulation well 03RW0003 was 940 ug/L. The influent concentration at this same well was 1200 ug/L on April 24. Influent concentrations at this circulation well, 03RW0003, ranged from a low of 520 ug/L on March 12 to a high of 1700 ug/L during the following week of March 5. At the other NoVOCs circulation well, 03RW0004, the initial TCE influent concentration was 520 ug/L on February 26 and was 570 ug/L on April 24. At this circulation well, 03RW0004, the influent concentrations ranged from a low of 380 ug/L on March 28 to a high of 710 ug/L on March 5. Since data was not available for the first 45 days of operation it is unknown if these concentrations represent a drop in the initial concentrations or not.

One possible explanation for the lack of an apparent decrease in the influent concentration at the NoVOCs, CS-10 South location, was that the concentration of TCE entering the circulation wells were increasing. The upgradient TCE concentration, represented by monitoring well MW0209D, appeared to increase from an initial baseline concentration of approximately 620 ug/L to 1000 ug/L

after the fourth round of groundwater sampling. However, this same trend in changes of TCE concentration was not observed at the deeper interval, MW0209E. The initial TCE baseline concentration at MW0209E was 430 ug/L and decreased to 280 ug/L during the April groundwater monitoring event. Since the influent data at the circulation wells were not available it cannot be determined if the change in upgradient concentration was a factor in not observing an apparent decrease in circulation well influent. However, with an increase in one upgradient monitoring well interval, MW0209D, and a decrease in the other upgradient monitoring well interval, MW0209E, it is possible that the overall effect was to maintain a constant concentration moving into the circulation well.

It is also possible that, since the location of MW0209 is not directly upgradient to 03RW0003 and 03RW0004, the true upgradient concentration could be higher than what is represented by the available data. However, if the real upgradient concentration is reasonably close to the concentration at MW0209, then the influent concentration in the circulation wells would be expected to decrease because clean, treated water is circulated back to the intake of each circulation well. Since this change was not observed, the influent data for the NoVOCs site does not appear to strongly support the premise that a circulation cell had developed. It does not necessarily mean that that a circulation cell does not exist. It is possible that the groundwater concentration that migrated into the cell increased, masking the decrease that would otherwise have been observed and expected. It is also possible that the circulation cell did not fully develop properly due to the amount of downtime that occurred. The downtime was between approximately 45% (57.5 days/127 days) for 03RW0003 and 48% (61.5 days/127 days) for 03RW0004.

The changes in monitoring well concentration data versus time were evaluated to assess various hypotheses regarding the existence and extent of a circulation cell. The decrease or increase in TCE concentration in the aquifer could be used as evidence used to infer that a cell had formed. Concentrations of TCE in monitoring wells within the circulation cell are expected to generally decline, especially for those wells that are close to the discharge screens. A decrease in concentration could suggest that cleaner water exiting the circulation well had displaced the aquifer water of higher concentration. Although this was observed in some wells, it was not consistent throughout all the wells within the circulation cell, especially in the wells that were screened at the depths close to the intake screens.

Data from the UVB site, located at the CS-10 North, was reviewed to determine if the data supported the premise that circulation was occurring. Monitoring well MW0202D, screened at a depth of -75 to -80 feet msl, located approximately 20 feet crossgradient from the UVB circulation well 03RW0001 would be expected to be within the circulation cell. This depth corresponds to a point between the discharge point of the upper circulation cell, located at -46 to -56 msl, and the

intake point for the upper circulation cell, located at the -96 to -106 msl depth. Piezometeric head measurements for MW0202D were -0.032 feet lower than at static conditions, suggesting that flow should be downward from the discharge zone to the intake zone. This location is within the area of influence of the circulation well, is above the top of the intake screen, and is below the bottom of the discharge screen. It would be reasonable to assume that this location would represent a zone where circulation from the discharge zone to the intake area would occur. Intake of water outside of the circulation cell would be expected to move into the intake zone along streamlines that are below this point, thereby minimizing the interaction of treated water with non-treated water. The concentration of water that had been treated and released would be expected to be low in TCE. It would be reasonable to expect that as the treated water moves past this point, the concentration of TCE would decrease if the conceptual model of the circulation cell is as envisioned.

The concentrations of TCE at MW0202D have remained constant or increased slightly over the four rounds of sampling. Since the concentration is not decreasing, circulation of clean, treated, water does not appear to be occurring in the upper zone. The lack of circulation flow at this location could be due to the layer of silt, classified as ML in the boring log for MW0202, that was identified to be present just below the D screened interval. It is possible that this thin low hydraulic conductive layer may be retarding the migration of water to the intake portion of the upper circulation well. This may be sufficient to cause preferential flow from upgradient, contaminated groundwater into the intake screen. Without an observed decrease in concentration in this well, that would occur if clean treated water is being circulated back into the intake screen, the premise that circulation is occurring could not be substantiated.

The groundwater impacted with TCE at this location are mostly in the deeper portions of the aquifer. Although the upgradient monitoring well, MW0201, is not directly upgradient of 03RW0001, it does nonetheless support the position the groundwater plume is in the lower portions of the aquifer. For example, the only zones that are impacted at the upgradient well, MW201, are the two deepest zones, E, located between -100 to -105 msl, and zone F, located between -135 and -140. For a GCW technology to be successful in capturing the deep portion of the plume, the plume would need to move up to the intake screen of the bottom circulation cell, which is located at the -112 to the -122 msl depth. It is also possible that the circulation well has created an hydraulic barrier to contaminant movement, diverting water around the increased pressure at the discharge screen. If the negative pressure at the intake screen is dissipated over a short distance from the intake screen, contaminated groundwater at the deeper portions of the aquifer may not be adequately drawn into the circulation well. For example, at MW0202G, the deepest screened interval, -165 to -170 msl, the concentrations of TCE have decreased from approximately 435 ug/L to 50 ug/L. The screened interval of MW0202G is therefore below the bottom of the screened intake zone of the bottom circulation cell. The observed decrease in concentration may be due to displacement of the

contaminated water at the lower circulation well discharge area by treated circulation well water. The question is where does the contaminated water go. If this water does not move vertically upward approximately 50 feet to the intake screen, then it will be released downgradient and will not be sufficiently treated.

A similar effect is observed at the other UVB circulation well, 03RW0002. At this location, MW0206, the two deepest zones are Zone F, located between -135 and -140 msl and Zone G, located between -165 to -170 msl. Zone F is located between the intake screen of the lower circulation well, located at the -112 to the -122 msl depth, and the discharge screen of the lower circulation well, located at the -152 to the -162 msl depth. At MW0206G, the deepest screened interval, -165 to -170 msl, the concentrations of TCE have remained constant, beginning at approximately 600 ug/L prior to the test and ending at 600 ug/L at the last round. This would suggest that the circulation has no effect on the contaminated zone represented by the interval at MW0206G. A lower piezometeric head than what was measured at static conditions was measured at this location which is not well understood since this location is below the discharge zone of the lower circulation well. At MW0206F, a decrease in TCE concentration was observed from an initial value of 2,300 ug/L to a value of approximately 300 ug/L. This decrease is also probably due to the displacement of contaminated water at the lower circulation well discharge area with treated circulation well water. It is not clear where water at this location would go as piezometeric head data for this location was unavailable. A silty sand lens, above this interval, was noted in the well logs for MW0206 that could affect the migration of TCE.

Finally, the concentrations of TCE at a downgradient location, MW0203E, located at the -100 to the -105 msl depth, have also remained constant over the four rounds of sampling. Since the concentration is not decreasing, circulation of clean, treated, water from the upper discharge zone does not appear to be extending out to this location where it would have been expected to. Although the piezometeric head at this location was less than static conditions by 0.208 feet, it was unclear why the expected decrease in TCE concentration did not occur. The decrease in piezometeric head does support the contention that flow is probably toward the intake screen of the circulation well 03RW0001, which is only 30 feet away. The question is where does the water originate from. One possible explanation, suggested by NoVOCs, is that untreated contaminated aquifer may be drawn into the intake screen from an area around the discharge zone, i.e. the "backdoor effect". Under this scenario contaminated groundwater flowing along the edges of the capture zone initially passes by the circulation well but is captured on the downgradient side of the circulation well due to the decrease in head caused by the pumping well. If the more contaminated groundwater concentrations were along the edges of the capture zone then this water could be causing the lack of change of influent concentration. However, this would support the premise that horizontal capture is occurring. Although the "backdoor effect" may explain the lack of observed concentration changes

in the area of the intake area of the circulation well it does not provide support for vertical flow that is required for circulation. The panel did not find adequate support for the premise that, at the CS-10 UVB location, circulation of treated, effluent was occurring.

The data collected for the NoVOCs system located at CS-10 South was also evaluated for consistency with the hypothesis that circulation is occurring. The monitoring well MW0210 at the D level is screened at a depth of -105 to -110 feet msl and is located approximately 20 feet downgradient from the NoVOCs circulation well 03RW0003. The concentration data collected from this monitoring location would be expected to be within the influence of a circulation cell. Concentration changes at this location would provide information that could be interpreted as being consistent with whether or not a circulation cell had been established. This depth corresponds to a point between the location of the discharge screen of the circulation well, located at -80 to -95 msl, and the intake screen of the circulation well, located at the -140 to -155 msl depth. Piezometeric head measurements for MW0202D were slightly lower than at static conditions and the locations above the D location were higher than static suggesting that flow should be downward from the discharge zone to the intake zone, as expected. Since this location is within the area of influence of the circulation well and is below the bottom of the discharge screen, it would be reasonable to assume that this location would represent a zone where flow from the cleaner discharge zone to the intake area would occur. The concentration of TCE in water that has been treated and released would be expected to be less than at initial conditions. This change in the concentration of TCE should be expressed as a continual decrease in concentration of TCE over time if the circulation cell is behaving as envisioned.

The data indicates that the concentrations of TCE at MW0210D have decreased over the four rounds of sampling rounds from an initial concentration level of 740 ug/L to 83 ug/L. This concentration decrease could be due to the circulation of clean, treated, water within the cell or could be due to the migration of cleaner aquifer water from other areas of the aquifer to the circulation cell. The source of the clean water, whether it is from the discharge zone of the circulation cell or from another portion of the aquifer that is less impacted, cannot be determined from this information. Although, the data does appear to be consistent with vertical flow, required for circulation to occur, the data is also consistent with horizontal flow. Flow may be moving horizontally along a zone of low permeability with no or little migration vertically. Although the monitoring well log for MW0210D was unavailable, the cross-section that included MW0210D indicates that this well and the circulation well, 03RW0003, are screened in geological material similar to 03PZ0217. The lithography at 03PZ0217 was shown in more detail on the geological cross-section that was provided. Several layers of low permeability geological material, described in the logs as ML (i.e. inorganic silts, very fine sands, silty or clayey fine sands) were identified in the portion of the aquifer screened near the D level. One low permeability layer in 03PZ0217, near the

D level, was logged as ML/SM and was located between -100 and -105 msl. If projected out to MW0210D and 03RW0003, this layer would be just below the discharge screen interval which is between -80 and -95 feet msl. The ability to move water through these layers is what is in question. If treated water is released from this upper screened interval it is possible that the water may move horizontally along the top of a low permeability layer instead of vertically.

The panel noted that there is a limited amount of actual permeability data for these layers. The permeability of many of these aquifer layers have been estimated from an understanding of the grain size of the material in question. In some cases the material classification has been made from visual observations of a geologist or a geological engineer. In other cases a grain size analysis was performed. However, since these layers may be thin it is difficult of accurately collect a sample of this material for analysis. The panel noted that during the modeling, many of these low permeability layers were averaged over a larger, more permeable thicker zone. In this instance, the effect of these thin, yet important, zones in limiting the vertical movement of groundwater would be neglected and the groundwater model would produce a picture of circulation that is not representative of actual site conditions. A more refined groundwater model that accounts for the presence of these low permeability zones was suggested.

The panel felt that groundwater, migrating horizontally above or below these intervals, could provide piezometeric head measurements that were consistent with either direction. Without tracer information to supplement the piezometeric head data, the direction of groundwater movement, i.e. vertically or horizontally, could not be ascertained. The combination of piezometeric head data, tracer information and concentration data that are consistent with each other and consistent with vertical flow would be required to formulate a complete and accurate understanding of how groundwater moves both vertically and horizontally in the circulation cell.

The geologic material that this well and the circulation well is screened in is comprised of several layers including silt, sandy silt, clayey silty sand and clayey silt. Although the well log for MW0210 was not available, the log for the piezometer, PZ0217, located further downgradient of MW0210, did indicate that low permeability layers were present at the D interval. This data suggests that increased anisotropy in the area between the discharge zone and the intake zone of the circulation well may be impediments for the development of a circulation cell. Similar data is noted for the monitoring well, MW0211, located approximately 30 feet downgradient of the circulation well. At this location, the concentration of TCE in the C layer dropped from 600 ug/L to 72 ug/L. The decrease in concentration was more pronounced at the deeper E layer where the concentration dropped from 2200 ug/L to 120 ug/L. Although the boring logs for these two monitoring wells, MW0210 and MW0211, were not available, changes in the geologic strata with depth are likely.

At the F level, the concentration of TCE in the monitoring wells MW0212 and MW0214, both screened at a depth of -145 to -150 feet msl, increased over time. At MW0212F, the initial TCE concentration of 210 ug/L increased to a high of 1900 ug/L during the third month of groundwater monitoring and was 1500 ug/L during the most recent sampling event, the fourth month. At MW0214F the initial TCE concentration of 610 ug/L increased to a high of 1800 ug/L during the second month of groundwater sampling and was 1300 ug/L during the most recent period, the fourth month. MW0212 is located approximately 50 feet downgradient from the NoVOCs circulation well, 03RW0003, and 50 feet upgradient/sidegradient of the NoVOCs circulation well, 03RW0004. This well is expected to be within the circulation cell. The F level depth corresponds to a zone at the intake point for the circulation well, which is screened at the -140 to -155 msl depth. Piezometeric head measurements for MW0212F and MW0214F were lower than at static conditions, approximately 0.35 to 0.45 feet lower, suggesting that flow should be to the intake screen. However, if flow was downward from the discharge zone to the intake zone, as would be expected if circulation was occurring, then it would be reasonable to expect that the concentration of TCE would decrease. This would be even more likely for MW0212F which is downgradient from the other circulation well, 03RW0003. MW0214F is 15 feet away from the circulation well 03RW0004 and should be expected to be within the area of influence of this circulation well. This location could represent a zone where flow from the cleaner discharge zone would migrate to the intake area. It is possible for a zone of TCE contaminated water to migrate into the intake screen of 03RW0004 lower than the influence of the circulation cell. The circulation cell may be above the F level monitoring point, however, this would mean that the data from MW0212F and MW0214F would not represent conditions of circulation.

The panel generally believed that some circulation flow was probably occurring in both systems, however, the extent of circulation or the zone of capture could not be determined with certainty. The panel felt that N could be as low as 0.1 or lower, or as high as 1, but probably not much higher.

It should be pointed out that both vendors believe strongly that the pressure and concentration data collected to date is adequate to prove circulation cell development. This is a point of disagreement, as the panel unanimously believed that the data is not adequate. The difference lies in the degree of credibility given to the modeling. The panel did not believe that without empirical data the contention that circulation cells develop can be proven based upon modeling alone. The panel believed that the best empirical approach would include tracer studies, which have not been done.

The panel did feel that circulation wells, as designed at MMR, did not cause a significant drop in groundwater levels. Additionally, there is little doubt that the circulation wells are removing mass from aquifer. The concentration of TCE in the effluent of the circulation wells is above the target

concentration that would be required for containment of the plume. The downgradient concentration of TCE that would be released from the circulation cell is not currently known.

## 3.2 MASS BALANCE

A mass balance is a useful tool to ensure that the interpretation of other data is consistent. There are three different mass balances that can be estimated around the pilot systems, the first two being essential. The first mass balance examines the concentration and flow rate in the extracted vapor to determine the number of pounds per day of contaminant removed from the system. The second is the concentration and flow rate influent and effluent to the well to determine the number of pounds of material removed in the well. The third mass balance is to make an estimate of the number of pounds of hydrocarbons within the radius of influence in the aquifer (usually based on groundwater concentrations observed in the monitoring wells, and some estimate of the zone of influence) for comparison to the amount being removed. However, the third mass balance is the most difficult to do accurately because the radius of influence and mass moving into the well are unknown. The first two mass balances, based on gas flow, water flow, and their concentrations, should agree fairly closely. If they do not, this is a red flag. These mass balances should then be compared to the estimated mass removal from the aquifer. These comparisons should probably agree within an order of magnitude. Some mass balance/mass removal estimates have been for CS-10 North and South. Because the system has not been operating long enough and not enough data has been collected, no mass balance/mass removal estimates have been completed for the Ashumet Valley circulation system.

### 3.2.1 CS-10 NORTH

SBP estimated the total TCE removed from the CS-10 North system based on the influent concentration and flow rate in the extracted vapor.

| Circulation. Well | Sampling Dates | Avg. air flow (cf/min) | Avg. air conc. (ng/lit) | grams TCE removed |
|---|---|---|---|---|
| 03RW0001 | Dec 21 to Jan 3 | 650 | 5,450 | 2,019 |
| 03RW0002 | Dec 21 to Jan 3 | 650 | 5,820 | 2,156 |
| 03RW0001 | Jan 4 to March 4 | 720 | 3,900 | 6,173 |
| 03RW0002 | Jan 4 to March 4 | 720 | 1,910 | 2,799 |
| 03RW0001 | March 5 to March 15 | 1,200 | 2,000 | 977 |
| 03RW0002 | March 5 to March 15 | 1,100 | 1,700 | 761 |
| 03RW0001 | March 15 to May 12 | 1,100 | 1,800 | 4,756 |
| 03RW0002 | March 15 to May 12 | 1,050 | 1,600 | 4,036 |
| | | | | |
| 03RW0001 | 137 days | | subtotal | 30.8 pounds |
| 03RW0002 | 133 days | | subtotal | 21.5 pounds |
| | | | **TOTAL** | **52.3 pounds** |
| | | | **TOTAL** | **.19 lbs/day/well** |

Jacobs Engineering estimated mass removal at CS-10 North by examining the flow rate and concentration of the influent and effluent groundwater at the circulating wells. Jacobs Engineering' estimate included allowances for system downtime, variations in pumping rates for each well, and variations in influent and effluent concentrations. Pumping rates varied between 40 and 60 gallons per minute, influent concentrations varied between 84 and 730 micrograms per liter, and effluent concentrations varied from 4.4 to 120 micrograms per liter. The following assumptions were made: the flow at the influent screens is equal to that at the effluent screens, and the influent and effluent concentrations at each circulating well are used as average concentrations over the time period between sampling events.

| Circulation Well | Sampling Dates | Operating Time | Mass of TCE Removed (pounds) |
|---|---|---|---|
| 03RW0001 | Dec 21 to April 14 | 105.25 days | 20.70 |
| 03RW0002 | Dec 21 to April 14 | 103.9 days | 12.25 |
| | | **TOTAL** | **0.16 lbs/day/well** |

Although the SBP and Jacobs Engineering mass removal estimates are taken over slightly different time intervals during the pilot testing program, the panel is concurred with the calculations, and believed that they are in sufficient agreement to support reasonable removal estimates. No attempt

was made to estimate mass balances from the aquifer based on monitoring well groundwater concentrations.

### 3.2.2 CS-10 SOUTH

The mass removed can be estimated using groundwater flow data and influent and effluent concentration data. It is also possible to determine mass removed by knowing the air flow and the before and after concentration of contaminants in the air stream. However, it was not possible to estimate the total mass removed by the NoVOCs system at the CS-10 South site because much of this data were not available. Jacobs Engineering estimated mass removal at CS-10 South by examining the flow rate and concentration of the influent and effluent groundwater at the circulating wells for recent data. Jacobs Engineering' estimate included allowances for system downtime, variations in pumping rates for each well, and variations in influent and effluent concentrations. Pumping rates varied between 150 and 180 gallons per minute. Influent concentrations varied between 520 and 1700 micrograms per liter, and effluent concentrations varied from 43 to 110 micrograms per liter. The following assumptions were made: the flow at the influent screens is equal to that at the effluent screens, and the influent and effluent concentrations at each circulating well are used as average concentrations over the time period between sampling events.

M&E provided an estimation of mass removed from the NoVOCs system that is presented below. This data is for the operational period between December 21, 1996 and February 19, 1997.

| Circulation Well | Sampling Dates | Operating Time | Mass of TCE Removed (pounds) |
|---|---|---|---|
| 03RW0003 | Dec 21 to Feb 19 | 37.25 days | 80.46 |
| 03RW0003 | Feb 20 to April 24 | 47.5 days | 104.34 |
| 03RW0004 | Dec 21 to Feb 19 | 33.5 days | 37.85 |
| 03RW0004 | Feb 20 to April 24 | 46.5 days | 45.58 |
| | | **TOTAL** | **1.63 lbs/day/well** |

M&E/EG&G Environmental computed contaminant mass removal in the aquifer assuming dissolved TCE is homogenous throughout the treatment zone, the treatment zone is 400 feet long by 250 feet wide by 120 feet thick, the mass distribution is 50% dissolved, 50% adsorbed, and the porosity is 0.25. TCE concentrations were assumed to be 1,170 ug/L for the baseline, 490 ug/L for Month 1, 410 ug/L for Month 2, 310 ug/L for Month 3, and 275 ug/L for Month 4. Therefore, 341.5 pounds of TCE were estimated to have been removed from the aquifer over the duration of the pilot test. Using 165 days of operation for CS-10 South, it was estimated that each circulation well removed **2.07 pounds per day** of TCE.

The mass balance estimates done appear reasonable, but the lack of vapor data leaves the NoVOCs analysis broader than the UVB analysis.

## 3.3 PILOT SYSTEM COMPARISONS

Based on the existing level of pilot test data, the panel could not determine which technology, UVB or NoVOCs, is more effective. Both technologies were able to achieve greater than 90% stripping efficiencies, although the UVB system was required to install a double stripper reactor to attain this level of stripping performance. Prior to the installation of the double stripper reactor, the UVB system was attaining only 80% stripping removal. However, without the ability to determine whether or not the circulation cell had developed the panel felt that overall system performance could not be evaluated. This is because each GCW technology requires multiple passes to achieve increased treatment performance. If circulation cannot be determined then the systems, as designed, cannot be fully compared.

There are notable differences between the technologies within the inside of the circulation wells. The question of whether or not circulation cells are created is more significant and this answer should be the same, independent of what technology is occurring within the well. If GCW technology is determined to be appropriate, then the efficiency of the in-well treatment process in addition to the cost required to install and operate the system should be the difference between the two systems. The specific MMR pilot designs were not entirely technology driven but reflected the engineers' interpretation of the site and how the technology should be applied. The panel felt that if the pilot systems traded testing locations, it would be likely that similar performance data would have been obtained. The primary reason the NoVOCs wells removed more mass was that they were placed in a more contaminated portion of the groundwater system and utilized higher pumping rates, not that it operated more efficiently than the UVB wells.

## 3.4 ADDITIONAL DATA NEEDS

The panel recommends that sampling of off-gas from the NoVOCs system begin immediately. The panel recognized that additional pilot test data will be collected in May and June 1997, and additional modeling will be conducted. However, the general consensus was that this would not likely make a difference in the panel's conclusions.

The panel felt that the most appropriate application of GCW technology is to remove sorbed contaminants from a source of continued groundwater contamination. GCW technology relies on the vertical flow of treated water that will promote the desorption of contaminants from soil. Mass

is continually removed in the GCW technology process and tends to isolate the area to be flushed. This lessens the potential for migration of contaminants from the source area to other non-contaminated areas of the aquifer. The use of GCW technology as part of a plume containment strategy was not considered appropriate at MMR due to the uncertainties with establishing and proving that a vertical circulation cell had sufficiently developed or was circulating the required quantity of treated groundwater while continually capturing the incoming plume. As a result, the panel felt that continuation of the pilot studies at MMR was unnecessary. Although a tracer study would provide the essential data necessary for determining whether or not a vertical circulation cell was operating as intended, the panel qualified their recommendation for performance of a tracer study, since they felt that GCW technology not applicable at MMR. However, if it was determined that the pilot study should continue and GCW technology was to be an integral part of a remedial strategy at MMR, tracer studies should be considered to evaluate the performance of GCW technology.

Additionally, it was the panel's opinion that determining GCW technology performance by numerical groundwater modeling would be too uncertain given the geological lithography at MMR. The determination of the zone of influence appeared to require additional monitoring wells at greater spacing than what is currently used. However, the panel did not determine the actual number or location of these additional monitoring wells. The twelve (12) supplemental monitoring wells that were to be installed during May will provide some of this data, although some additional wells would be required especially in lieu of conducting a tracer study. The number and spacing of these additional wells could be determined from an analysis of the actual hydraulic and concentration monitoring data that has been obtained since December, 1996. Data gaps identified during this evaluation should serve as the basis for further refining the understanding of circulation. Some of this analysis has been described in Section 3.1 and could be used as the basis of identifying further data needs.

## 3.5 USE OF PILOT SCALE TESTING FOR SCALE-UP

The panel felt that the optimal well spacing configuration or pumping rates could not be determined for any of the pilot systems, in part, because there was not enough data to prove that circulation cells were established.

# 4.0 RECOMMENDATIONS AND CONCLUSIONS

This section provides the panel's recommendations and conclusions regarding GCW technology at MMR. In addition to the evaluation of GCW technology at MMR, the approach that was used to evaluate the technology cannot be overlooked. The panel was not critical of how the pilot test was conducted, to the contrary, the panel recognizes that the MMR pilot was conducted in a state-of-the-practice fashion. Rather, the lessons learned in this pilot, and other similar pilot programs should be gathered and provided for future pilot efforts. This information will ensure that future pilot studies will collect the essential data needed to make an appropriate technology evaluation and are performed in an efficient manner. **Section 4.3** provides the panel's recommendation for future pilot studies.

## 4.1 EVALUATION OF GROUNDWATER CIRCULATION WELLS

This section addresses the potential applicability of circulation wells as a part of MMR's remedial plan. Although it is based in part on lessons learned in the pilot test, the discussion is independent of the apparent successes or failures of the pilot test. One key to determining the utility of any technology is cost. The expert panel did review preliminary cost estimates for ETR provided by Jacobs, and for GCW technology provided by the vendors. It was concluded that these preliminary cost estimates were not based upon similar assumptions and, therefore, not directly comparable. The panel does have expertise on the cost of implementation of ETR, recirculation wells, and other related remedial systems. Therefore, the panel did review aspects of circulation wells looking for "obvious" cost savings over ETR. When conclusions are drawn, these are based upon the panel's considered opinion and not on a detailed cost comparison. When comparisons are made between circulation wells and other technologies, generally the bench mark technology is ETR.

### 4.1.1 ADVANTAGES

The panel recognized that GCW technology has a number of potential advantages over ETR. Potential advantages often touted by vendors of circulation wells include :

- Energy savings associated with not pumping groundwater to the land surface from deep wells,
- No reinjection permit may be required as groundwater is treated in-situ, via a low profile system with components predominately underground,
- Vertical flow increases contaminant removal efficiency and increases mass removal in highly contaminated soils, and
- The impact on depression of the water table is minimal.

Other potential advantages include :

- Increased biodegradability of oxygenated water (applicable if target chemicals are aerobically biodegraded),
- Increased contaminant mass removal, and
- Lower cost than conventional pump and treat systems.

In reviewing these typical advantages, the panel concluded that these advantages were not clearly applicable to conditions at MMR. Energy savings associated with less pumping do not appear to apply because the water is essentially already pumped nearly to the land surface by both systems. Although the water table is generally between 50 to 70 feet below land surface (bls), it is approximately 40 to 45 feet at the CS-10 North location and less at the CS-10 South location. However, since the systems require lifting water to near the ground surface the benefits gained by performing treatment deep in the well are not realized at MMR. Additionally, the systems are designed to circulate the same water a number of times, apparently because of the low stripper efficiency. The panel believes the energy cost of a single pass pump and treat with high efficiency counter-current air stripping could be less.

Next, the lack of a requirement for injection permitting of a circulating well is the result of a regulatory loophole. At many sites, since water does not break the ground surface, regulators forgo the injection permitting requirements. The panel believes the number of wells and scale of application at MMR negate this benefit. The degree of regulatory attention focused on MMR will require that any reinjection, regardless of technique, be looked at closely. The panel also concluded that an ETR system could probably be designed to have a profile as low as the circulation wells at MMR. It was also concluded that a properly designed ETR could also produce minimal impacts on the water table, and since TCE degradation is mostly anaerobic so oxygenating the captured water (which has a high dissolved oxygen content to begin with) is probably not beneficial.

This leaves the increased efficiency/mass removal argument. As already discussed, increased mass removal is only a potential benefit and only applicable in highly contaminated soils, such as would be the case in a DNAPL contaminated source area. The panel could not find a location at MMR where this appears to be the case. The panel could not see how circulation cells could increase treatment efficiency at MMR. The only apparent rationale for circulation cells is to allow multiple water passes through the stripper. The panel believes that similar or better treatment efficiency could be obtained in a one pass ETR system with a higher efficiency counter current flow stripper.

The panel did not believe that, over an operational lifetime, circulation wells could remove more mass than an ETR system. This may be the case in a source area with high soil contaminant

concentrations, but not in the MMR plumes. It was not clear to the panel how circulation wells could result in a cost savings as compared to ETR at MMR. In a component to component comparison, it appeared to the panel that, if anything, circulation wells may be more expensive to achieve the same goals. The panel, however, did not perform any detailed cost analysis and simply recommends that MMR look closely at the cost issue before assuming that circulation wells will save money.

### 4.1.2 DISADVANTAGES

A number of potential disadvantages of circulating well technology were identified by the panel. These include the fact that contaminant capture and adequate treatment requires the development of a circulation cell. Circulation cell development is highly sensitive to geologic conditions such as variations in vertical permeability relative to horizontal hydraulic conductivity. These factors are difficult to characterize and project across the site. This point can be seen in the MMR pilot testing. Despite a large scale and expensive effort, the existence of circulation cells could not be determined, let alone their performance evaluated. By comparison, ETR technology is more easily and reliably pilot tested, modeled, implemented, and monitored.

In addition, other potential disadvantages identified by the panel were that it is difficult to demonstrate and prove the zone of capture, low stripping efficiency may result in the need for more wells and/or a second fence, more recycling, and reinjection of water above the maximum contaminant levels (MCLs). Furthermore, in-well, co-current air strippers are less efficient than counter-current units of similar size.

Circulation wells also have limited flexibility in separating extraction from injection points, extraction must equal injection at each well, there could be possible leakage or short circuiting, and component and well replacement costs are potentially greater than an ETR system especially if injection points clog and the entire circulation well has to be replaced. An ETR reinjection well can be replaced at less cost because it is a shallower and smaller diameter well. Another potential disadvantage is that GCW technology are less commercially available than ETR. Understanding the circulation cell and modeling may be more complex (near field models in which layering and anisotropy are significant are more difficult to develop and calibrate), circulation technology requires the use of larger diameter wells, engineering and operation and maintenance (O&M) may be more difficult down hole than above ground, and performance monitoring data is more difficult to gather and interpret because of the circulation cell.

Although it is the panel's conclusion that circulation wells do not appear to have any advantage over ETR, the pilot test was useful in making that determination. The conclusions drawn about

circulation technology applied at MMR would not have been apparent without having gone through the pilot exercise and the panel review. The circulation wells did remove contaminant mass from the aquifer but, the panel believes that there may be a more cost effective and better technological approach to accomplish the same ends.

## 4.2 OTHER DESIGN OPTIONS

The expert panel evaluated other design options for plume containment and/or mass removal at MMR that may be able to achieve the same results at lower cost. The current pilot system relies on vertical circulation and multiple passes for its groundwater treatment. The panel concluded that vertical circulation is not necessary, or more beneficial for the case of capturing and treating a dissolved plume. A single pass treatment process can be utilized that will treat captured groundwater to MCL and will not rely on recycle to supplement treatment inefficiencies. The panel believes it may be more cost effective and feasible to engineer improved stripper efficiency than to achieve multiple passes of the collected groundwater. Furthermore, downhole air strippers appear to be more costly and difficult to maintain as compared to an aboveground modular high efficiency design.

A design alternative for MMR could include separate, decentralized, satellite extraction and injection fences at locations near where the circulation wells would be placed. The potential benefits include:

- One pass treatment with higher efficiency stripping (use of a counter-current rather than a co-current stripper) and lower cost than a downhole stripper,
- Increased flexibility as it is not necessary to reinject at the same rate or location as is required with GCW technology,
- Reduced costs of shallow injection well replacement due to fouling as compared to the cost of replacing the deeper and more expensive circulation well,
- Lower operation and maintenance costs as equipment is more accessible above ground,
- Lower initial capital cost (smaller diameter wells are less expensive and this may offset the cost of two wells versus one), and
- As long as the reinjection point is close to the extraction point, the water table can be maintained.

Air treatment possibilities would be the same for circulation wells, direct discharge, dry phase carbon adsorption of the stripper, and in-line aqueous phase carbon. The screen configuration would be sufficient to capture the plume. Water would be extracted from the contaminated zone and could be injected in the vadose zone or the clean aquifer above. The system would be designed to configure extraction and injection to protect the water table in ecologically sensitive areas.

## 4.3 DESIGN OF AN IDEAL CIRCULATION WELL PILOT TESTING PROGRAM AT MMR

The expert panel decided that it would be beneficial to take the lessons learned from the current circulating well pilot testing program in designing an ideal pilot test program for MMR. The panel is not necessarily recommending more pilot tests, but intends this discussion as a guide to others in designing future circulating well pilot testing programs.

### 4.3.1 MODELING

The panel concluded that the pilot test design should incorporate lessons learned from modeling studies prior to installation of an GCW technology pilot program. Although some information, such as vertical stratigraphy, may required some field data collection, much of this data should be obtained from available studies and investigations that have been performed. Performing modeling prior to conducting a pilot study will provide a basis for what is to be expected. Many of the input modeling parameters can be estimated from data logs or could be supplemented with some limited investigations. The model should be developed to provide answers to the following:

- The potential and time required for establishing a circulation cell and its configuration,
- The expected dimensions of the capture zone,
- The expected stagnation points,
- The residence time required in the capture zone, and
- The anticipated downgradient concentration reduction.

For inputs, the model requires an accurate determination of several aquifer parameters including :

- Vertical permeability of each layer,
- Stratification of the aquifer materials,
- Horizontal permeability, and
- Hydraulic gradient.

For sensitivity analysis, the panel is recommending varying the vertical hydraulic conductivity and stratification to determine how this affects the formation and functioning of the resulting circulation cell. Although it is important to focus on the issue of circulation cell formation as driven by vertical versus horizontal permeability and layering, the panel agrees that modeling can only study this issue. It was the panel's conclusion that the modeling has important but limited value. Without a well done tracer study, modeling alone should not be relied upon to answer this.

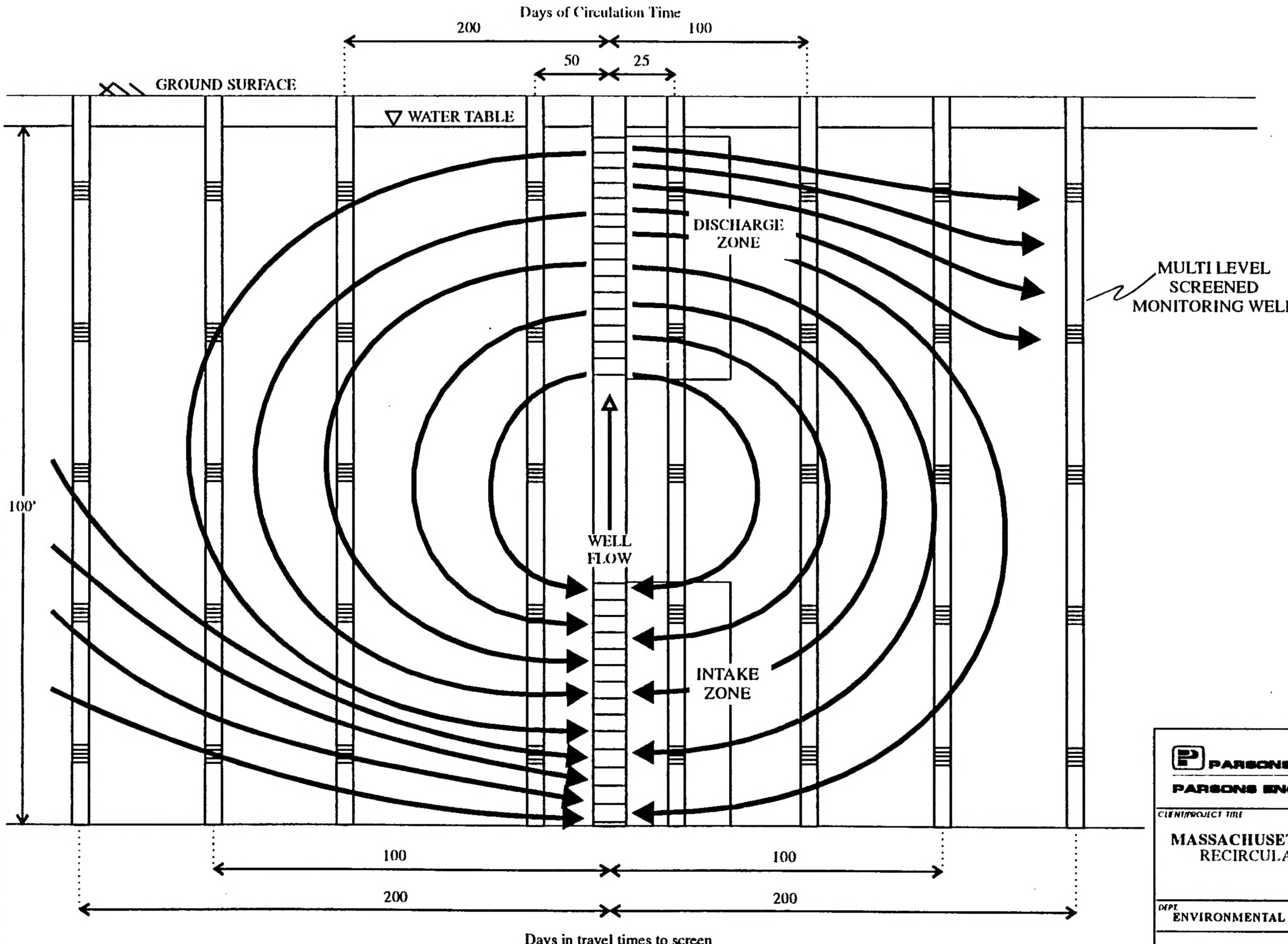
The panel concluded that only one circulation well should be installed for a pilot test. Data from one circulation well will provide the essential information needed to evaluate the performance of GCW technology regarding vertical flow, extent of capture, circulation ratios, upgradient and downgradient concentrations and stripping efficiencies at less cost and without the complicating variable added by the influence from another nearby circulation well. If only one circulation well is pilot tested the flow of groundwater will always be perpendicular to the direction of groundwater direction. The circulation well should be screened at the bottom and top of the aquifer with the bottom screen serving as the groundwater intake. Monitoring wells should be established at an estimated 100 and 200 days of natural groundwater travel time upgradient and downgradient of the circulation well. It is assumed that the well at 200 days downgradient is past the theoretical stagnation point. Additional monitoring wells should be installed 25, 50, 100, and 200 days of circulation time upgradient, downgradient, and cross-gradient (based on modeling estimates). All monitoring wells should be sampled and screened in as many layers as required to evaluate preferential flow caused by changing lithography. These distances should be estimated from the most probably case modeling. Please refer to the attached plan-view and cross-sectional drawing of an ideal pilot test for MMR. The pilot test should be run for one year and designed to obtain meaningful results in the first 30 days.

### 4.3.2 MONITORING

The monitoring scheme would begin with a groundwater flow direction survey. Baseline data would preferably be collected from a pilot location with over a years' worth of background data. Sampling parameters would include VOCs, dissolved oxygen, water levels, iron (if the area was anaerobic), and scaling and corrosivity properties in the monitoring wells and circulation well.

Upon system startup, real time pressures should be measured and groundwater chemistry should be collected monthly for at least four months. The system should be designed to include sampling ports to measure air flows and VOCs in the offgas daily for the first month and then weekly thereafter. Influent and effluent chemistry sampling and groundwater flow monitoring should be conducted on the circulation well groundwater.

Conservative tracer tests should be run. A one-day bromide tracer should be conducted within the circulation well to determine the net groundwater flow through the well. This test should be conducted every six months. To assess and define the circulation cell dimensions and flow strength, a one-time slug of a volatile tracer should be placed in the circulation well and would be monitored in the offgas. A non-volatile continuous diverging tracer would also examine the circulation cell. The non-volatile tracer would be looked for in the monitoring well.




PARSONS
PARSONS ENGINEERING SCIENCE, INC.

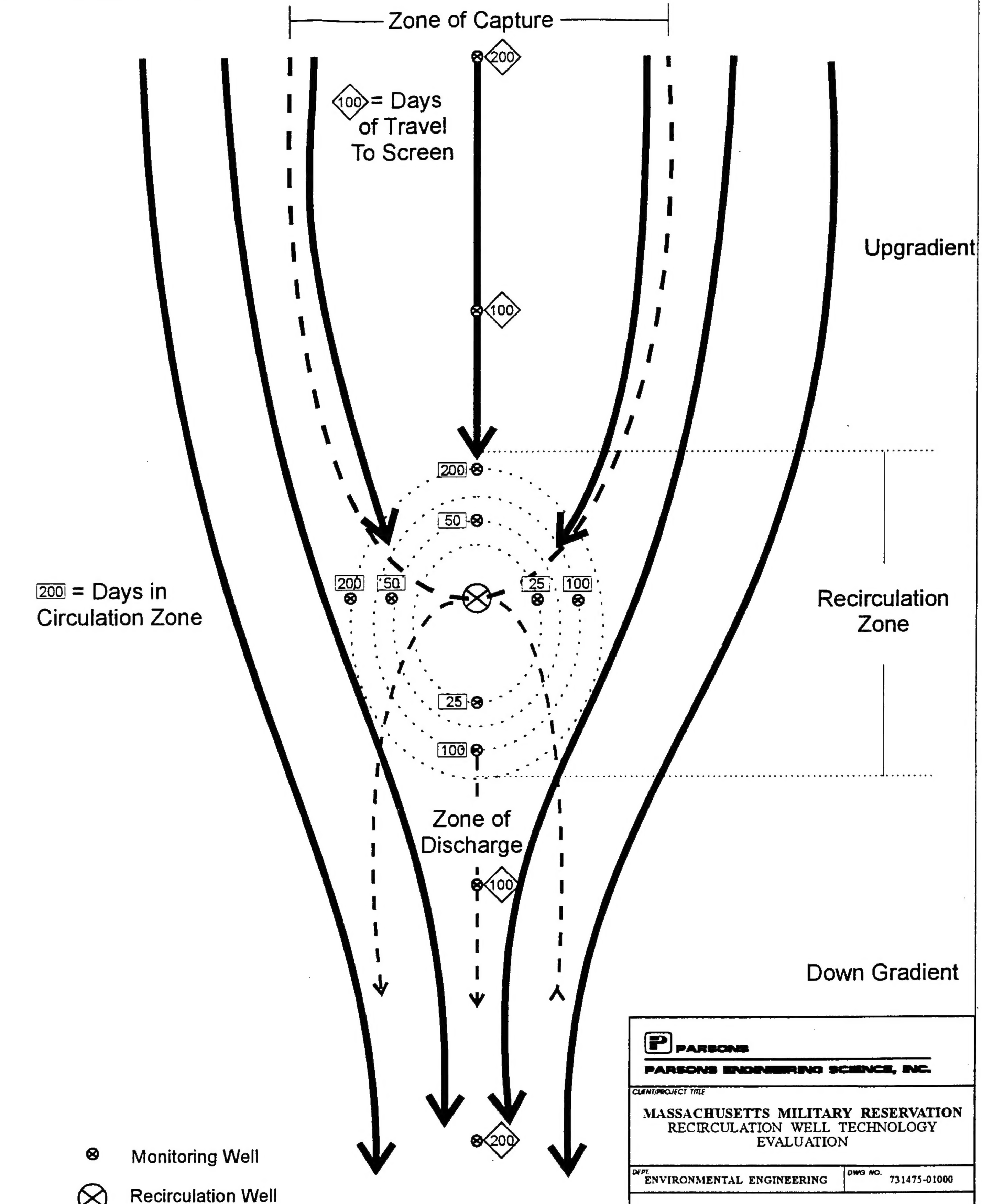
CLIENT/PROJECT TITLE
MASSACHUSETTS MILITARY RESERVATION
RECIRCULATION WELL TECHNOLOGY
EVALUATION

DEPT. ENVIRONMENTAL ENGINEERING
DWG NO. 731475-01000

IDEAL PILOT TEST
CROSS SECTIONAL VIEW
DEPLICTING
TRAVEL TIMES FOR
RECIRCULATION

SCALE NA
DATE JUNE 1997

GRAPHICS\MMRSECT.CDR




PARSONS
PARSONS ENGINEERING SCIENCE, INC.

CLIENT/PROJECT TITLE: MASSACHUSETTS MILITARY RESERVATION RECIRCULATION WELL TECHNOLOGY EVALUATION

DEPT. ENVIRONMENTAL ENGINEERING | DWG NO. 731475-01000

IDEAL PILOT TEST DEPICTING PLAN VIEW OF FLOW LINES FOR RECIRCULATION

SCALE NA | DATE JUNE 1997

GRAPHICS/MMRCONT.CDR

The panel recommends, that by varying the flow rates in the well in the short term, the pressure data could be evaluated. Otherwise, it was decided that no other flow rate tests should be conducted.

A second round of modeling would be completed to compare the original conceptual model against actual field measurements. If the model provided output as expected, it would then be used to design a scale-up at a worst, middle, and best case site. If the model did not work, the original conceptual model would have to be refined.

## 4.4 ADDITIONAL CONSIDERATIONS

The panel, in its review of pilot study at MMR, came up with some additional considerations that concern some broader issues.

- Based on the lessons learned in this effort, the panel has identified what we believe is an improved approach to circulation well pilot testing on a site like MMR. The panel, however, also came to the conclusion that circulation wells may not be the most cost effective approach to plume containment or treatment at MMR. The panel does not recommend that any additional pilot testing be done at MMR. However, if the decision is made to go forward with circulation wells at MMR, it is the recommendation of the panel that additional testing be done as outlined in **Section 4.3**.
- The panel believes that conducting a tracer test at MMR is only useful as an academic exercise and only applicable to the well where the tracer testing is conducted. The panel warns against extending knowledge from the tracer test to other wells at MMR and other sites. The panel has withheld recommendation to go forward with a tracer test at MMR because it was concluded that their is no obvious reason to proceed with the GCW technology.